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MINERALS YEARBOOK



U.S.
DEPARTMENT
OF THE
INTERIOR



BUREAU
OF
MINES

UNITED STATES DEPARTMENT OF THE INTERIOR • Bruce Babbitt, Secretary

BUREAU OF MINES

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

Foreword

This edition of the Minerals Yearbook discusses the performance of the worldwide minerals industry during 1991 and provides background information to assist in interpreting that performance. Content of the individual Yearbook volumes follows:

Volume I, Metals and Minerals, contains chapters on virtually all metallic and industrial mineral commodities important to the U.S. economy. Chapters on advanced materials and nonrenewable organic materials also were added to the Minerals Yearbook series beginning with the 1989 and 1990 volumes, respectively. A new chapter on nonferrous metals recycling has been initiated in this 1991 volume. In addition, a chapter on survey methods used in data collection with a statistical summary of nonfuel minerals and a chapter on trends in mining and quarrying in the metals and industrial mineral industries are included.

Volume II, Area Reports: Domestic, contains chapters on the minerals industry of each of the 50 States, Puerto Rico, Northern Marianas, Island Possessions, and Trust Territory. This volume also has a chapter on survey methods used in data collection, including a statistical summary of domestic nonfuel minerals.

Volume III, Area Reports: International, contains the latest available mineral data on more than 150 foreign countries and discusses the importance of minerals to the economies of these nations. Beginning with the 1989 review, Volume III is presented as six reports: Mineral Industries of the Middle East, Mineral Industries of Africa, Mineral Industries of Asia and the Pacific, Mineral Industries of Latin America and Canada, Mineral Industries of Europe and Central Eurasia, and Minerals in the World Economy. This year's reports incorporate location maps, industry structure tables, and an outlook section previously incorporated in our Mineral Perspectives Series quinquennial regional books, which are being discontinued.

The U.S. Bureau of Mines continually strives to improve the value of its publications to users. Therefore, constructive comments and suggestions by readers of the Yearbook will be welcomed.

Acknowledgments

Volume I, Metals and Minerals, of the Minerals Yearbook presents data on about 90 material commodities that were obtained as a result of the information gathering activities of the U.S. Bureau of Mines.

The collection, compilation, and analysis of domestic minerals industries data were performed by the staffs of the Division of Mineral Commodities and the Division of Statistics and Information Services. Statistical data were compiled from information supplied by mineral producers and consumers in response to canvasses, and their voluntary response is gratefully appreciated. Information obtained from individual firms by means of the U.S. Bureau of Mines canvasses has been grouped to provide statistical aggregates. Data on individual firms are presented only if available from published or other nonproprietary sources or when permission of the respondent has been granted.

The chapter "Survey Methods and Statistical Summary of Nonfuel Minerals" discusses in somewhat greater detail procedures for canvassing the minerals industry and the processing and evaluation of these data.

Other information appearing in the volume was obtained from the trade and technical press, industry contacts, and additional sources; this cooperation is gratefully acknowledged.

Statistics on world production were compiled in the Division of Statistics and Information Services and Division of International Minerals from numerous sources, including reports from the U.S. Department of State. U.S. foreign trade data were obtained from reports of the Bureau of the Census, U.S. Department of Commerce. Data on production costs for several commodities were supplied by the U.S. Bureau of Mines, Minerals Availability System.

The U.S. Bureau of Mines has been assisted in collecting mine production data and other supporting information by numerous cooperating State agencies. These organizations are listed in the acknowledgments of Volume II.

Donald G. Rogich
Chief, Division of Mineral Commodities

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SURVEY METHODS AND STATISTICAL SUMMARY OF NONFUEL MINERALS

By Jacqueline A. McClaskey and Stephen D. Smith

Ms. McClaskey, an operations research analyst with 6 years of Government experience, has been with the U.S. Bureau of Mines Branch of Statistics and Methods Development since 1990.

Mr. Smith, industry data analyst in the Section of Industry Data Analysis and Coordination, was assisted in the preparation of the Statistical Summary by Imogene P. Bynum, Chief, Section of Metals Data; Rosa McGee, Chief, Section of Industrial Minerals Data; William L. Zajac, Chief, Section of International Data; and Jim F. Lemons, Jr., Chief, Branch of Materials.

SURVEY METHODS

The U.S. Bureau of Mines Information and Analysis Directorate collects worldwide data on virtually every commercially important nonfuel mineral commodity. These data form the base for tracking and assessing the health of the minerals sector of the U.S. economy.

The Bureau's data collection activity was instituted by the 47th Congress in an appropriations act of August 7, 1882 (22 Stat. 329), which placed the collection of mineral statistics on an annual basis. The most recent authority for the U.S. Bureau of Mines survey activity is the National Materials and Minerals Policy, Research and Development Act of 1980 (Public Law 96-479, 96th Congress). This act strengthens protection for proprietary data provided to the U.S. Department of the Interior by persons or firms engaged in any phase of mineral or mineral-material production or consumption.

Data Collection Surveys

The Bureau begins the collection of domestic nonfuel minerals and materials statistics by appraising the information requirements of Government and private organizations of the United States. Requirements that can be met by collecting data from minerals establishments are posed as questions on U.S. Bureau of Mines surveys. Figure 1 shows a typical survey form.

Specific questions about the production, consumption, shipments, etc., of mineral commodities are structured in the survey forms to provide meaningful aggregated data. Thus, the entire mineral economic cycle from production through consumption is covered by 167 monthly, quarterly, semiannual, annual, and biennial surveys.

After the survey form has been designed, a list of the appropriate establishments to be canvassed is developed. Many sources are used to determine which companies, mines, plants, and other operations should be included on the survey mailing list. Bureau of Mines State Mineral Officers, State geologists, Federal organizations (e.g., Mine Safety and Health Administration), trade associations, industry representatives, and trade publications and directories are some of the sources that are used to develop and update survey listings. With few exceptions, a complete canvass of the list of establishments is employed rather than a sample survey. The iron and steel scrap industry is one of the exceptions where a sample survey is conducted.

The Paperwork Reduction Act requires that any Government agency wishing to collect information from 10 or more people first obtain approval from the Office of Management and Budget (OMB). OMB approves the need to collect the data and protects industry from unwarranted Government paperwork. (See *figure 1.*)

Survey Processing

The Bureau surveys approximately 25,500 establishments. Each year the Bureau mails about 50,000 forms that gather information for 167 different surveys. Each completed survey form returned to the Bureau undergoes extensive scrutiny to ensure the highest possible accuracy of the mineral data. The statistical staff monitors all surveys to ensure that errors are not created by reporting in physical units different from the units requested on the form. Relationships between related measures, such as produced crude ore and marketable crude ore, are analyzed for consistency. Engineering relationships, such as recovery factors from ores and concentrates, are also employed. The totals for each form are verified, and currently reported data are checked against prior reports to detect possible errors or omissions.

For the majority of the surveys, which are automated, the forms are reviewed to ensure that data are complete and correct before entering into the computer. The computer is programmed to conduct a series of automated checks to verify mathematical consistency and to identify discrepancies between the data reported and logically acceptable responses.

The U.S. Bureau of Mines is modernizing and automating all of its survey processing and data dissemination functions. Automated commodity data system functions include computerized preparation of statistical tables; the use of

desktop publishing to integrate text and tables; and the implementation of a microcomputer bulletin board, known as MINES-DATA, for electronic dissemination of minerals data.

Survey Responses.—To enable the reader to better understand the basis on which the statistics are calculated, each commodity annual report includes a section entitled "Domestic Data Coverage." This section briefly describes the data sources, the number of establishments surveyed, the response percentage, and the method of estimating the production or consumption for nonrespondents.

To produce reliable aggregated data, the Bureau employs efficient procedures for handling instances of nonresponse. Failure to return the initial survey form results in a second mailing of the form. If the second form is not returned, telephone calls are made to the nonrespondents. The followup calls provide the necessary data to complete the survey forms and/or verify questionable data entries. Periodic visits to important minerals establishments are also made by Bureau commodity specialists or State Mineral Officers to gather missing data and to explain the importance of the establishment's reporting. By describing the use of the published statistics and showing the impact of nonresponse, the Bureau strives to encourage respondents to give a complete and accurate reply.

The OMB "Guidelines for Reducing Reporting Burden" stipulates that the minimum acceptable response rate shall be 75% of the panel surveyed. In addition, the Bureau strives for a minimum reporting level of 75% of the quantity produced or consumed (depending on the survey) for certain key statistics. Response rates are periodically reviewed. For those surveys not meeting the minimum reporting level, procedures are developed and implemented to improve response rates.

Estimation for Nonresponse.—When efforts to obtain a response to a survey fail, it becomes necessary to employ

estimation or imputation techniques to account for missing data. These techniques are most effective when the response rate is relatively high. Some of the estimation methods depend on knowledge of prior establishment reporting, while other techniques rely on external information to estimate the missing data. When survey forms are received after the current publication has been completed, the forms are edited, necessary imputations are made for missing data, and the survey data base is updated. The revised data are reported in later publications.

Protection of Proprietary Data.—The U.S. Bureau of Mines relies on the cooperation of the U.S. minerals industry to provide the mineral data that are presented in this and other Bureau publications. Without a strong response to survey requests, the Bureau would not be able to present reliable statistics. The Bureau in turn respects the proprietary nature of the data received from the individual companies and establishments. To ensure that proprietary rights will not be violated, the Bureau analyzes each of the aggregated statistics to determine if the data reported by an individual establishment can be deduced from the aggregated statistics. If, for example, there are only two significant producers of a commodity in a given State, the Bureau will not publish the State total because either producer could readily estimate the production of the other. It is this obligation to protect proprietary information that results in the "Withheld" or "W" entries in the published tables. However, if a company gives permission in writing, the Bureau will publish the data as long as the data from other producers are protected from disclosure.

International Data

International data are collected by country specialists in the U.S. Bureau of Mines Division of International Minerals with assistance from the Section of International Data. The data are gathered from various sources, including published reports of foreign Government mineral

and statistical agencies, international organizations, the U.S. Department of State, the United Nations, the Organization of Petroleum Exporting Countries, and personal contact by specialists traveling abroad. Each February an annual "Minerals Questionnaire" is sent through the Department of State to more than 130 U.S. Embassies asking them to provide estimates of mineral production for the host country for the preceding year. Missing data are estimated by Bureau country specialists based on historical trends and specialists' knowledge of current production capabilities in each country.

Publications

The U.S. Bureau of Mines disseminates current and historical minerals information through a broad range of printed publications.

The Minerals Yearbook summarizes annually, on a calendar-year basis, the significant economic and technical developments in the mineral industries. Three separate volumes are issued each year: Volume I, Metals and Minerals; Volume II, Area Reports, Domestic; and Volume III, Area Reports, International. Chapters in these volumes are issued separately as annual reports before the bound volumes are available. (Volume III country reports appear in bound volume only.)

Volume I of the Minerals Yearbook presents, by mineral commodity, salient statistics on production, trade, consumption, reserves, and other measures of economic activity.

Volume II of the Minerals Yearbook reviews the U.S. minerals industry by State and island possessions.

Volume III of the Minerals Yearbook presents the latest available mineral statistics for more than 170 countries with a summary review of the role of minerals in the world economy.

Mineral Industry Surveys contain timely statistical and economic data on minerals. The surveys are designed to keep Government agencies and the public, particularly the mineral industry

and the business community, informed of trends in the production, distribution, inventories, and consumption of minerals. Frequency of issue depends on the demand for current data. Mineral Industry Surveys are released monthly, quarterly, semiannually, or annually.

Mineral Commodity Summaries, an up-to-date summary of about 90 nonfuel mineral commodities, is the earliest Government publication to furnish estimates covering the previous year's nonfuel mineral industry data. It contains information on the domestic industry structure, Government programs, tariffs, 5-year salient statistics, and a summary of international mining news.

State Mineral Summaries provide estimated data and summaries of mineral activities at the State level for the previous year. These summaries have been prepared in cooperation with State geological surveys or related agencies.

Minerals Today, published bimonthly, provides readers with the latest information about developments, trends, and issues concerning the mining, processing, and use of minerals and materials.

Metal Industry Indicators, published monthly, contains indexes that measure the current and future performance of four U.S. minerals industries. For each of the four industries, a composite coincident index and a composite leading index have been developed based on procedures and data similar to those used to construct the U.S. Department of Commerce's coincident and leading cyclical indicators for the national economy.

Information Circulars are primarily concerned with Bureau economic reviews and interpretative analyses. The series also includes surveys of mining and operating activities, guides to marketing of mineral commodities, and compilations of historical information and statistical and economic data on minerals.

To purchase Volumes I, II, and III of the Minerals Yearbook and Minerals Today, contact the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. For free copies of individual annual reports of the

Minerals Yearbook, the Mineral Industry Surveys, the Mineral Commodity Summaries, the State Mineral Summaries, and Information Circulars, contact Publications Distribution, U.S. Bureau of Mines, Cochran Mill Road, P.O. Box 18070, Pittsburgh, PA 15236. To receive a copy of the Metal Industry Indicators, contact the Branch of Statistics and Methods Development, U.S. Bureau of Mines, MS 9701, 810 7th Street, NW, Washington, DC 20241.

Electronic Data Dissemination

In addition to the Bureau's printed publications, current Mineral Industry Surveys for several commodities and selected annual reports from the Minerals Yearbook are now available through the Bureau's MINES-DATA computer bulletin board. Using this system, the public may obtain information up to 4 weeks before published copies of the reports would arrive in the mail. The MINES-DATA system may be accessed by calling (202) 501-0373 using a modem set to 1200 or 2400 baud, 8 data bits, no parity, and 1 stop bit. Further information on how to use the MINES-DATA system may be obtained from the system operator by calling (202) 501-0406.

STATISTICAL SUMMARY

This annual report summarizes data on crude nonfuel mineral production for the United States, its island possessions, and the Commonwealth of Puerto Rico. Also included are tables that show the principal nonfuel mineral commodities exported from and imported into the United States and that compare world and U.S. mineral production. The detailed data from which these tables were derived are contained in the individual annual reports of Volume I and in the State reports of Volume II of this edition of the Minerals Yearbook.

Although crude mineral production may be measured at any of several stages of extraction and processing, the stage of measurement used in this annual report is what is termed "mine output." It usually

refers to minerals or ores in the form in which they are first extracted from the ground, but customarily includes the output from auxiliary processing at or near the mines.

Because of inadequacies in the statistics available, some series deviate from the foregoing definition. For copper, gold, lead, silver, tin, and zinc, the quantities are recorded on a mine basis (as the recoverable content of ore sold or treated). However, the values assigned to these quantities are based on the average selling price of refined metal, not the mine value. Mercury is measured as recovered metal and valued at the average New York price for the metal.

The weight or volume units shown are those customarily used in the particular industries producing the commodities. Values shown are in current dollars, with no adjustments made to compensate for changes in the purchasing power of the dollar.

TABLE 1
NONFUEL MINERAL PRODUCTION¹ IN THE UNITED STATES

Mineral	1989		1990		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	
METALS							
Beryllium concentrates	metric tons	4,592	\$5	4,548	\$5	4,339	\$5
Copper ²	do.	1,497,818	4,323,965	1,587,742	4,311,204	1,631,078	3,931,305
Gold ²	kilograms	265,731	3,268,548	294,527	3,649,914	289,885	3,385,874
Iron ore (includes byproduct material)	thousand metric tons	58,299	1,839,873	57,010	1,740,925	56,775	1,674,100
Iron oxide pigments (crude)	metric tons	40,202	4,561	37,071	4,615	40,220	4,485
Lead ²	do.	410,915	356,477	483,704	490,771	465,931	343,948
Magnesium metal	do.	152,066	508,668	139,333	433,119	131,288	336,577
Mercury	do.	W	W	W	W	58	206
Molybdenum ³	do.	61,168	427,477	61,580	348,256	53,607	249,909
Nickel ore ⁴	do.	NA	NA	330	NA	5,523	NA
Palladium metal ⁵	kilograms	4,850	22,454	5,930	21,735	6,050	16,923
Platinum metal ⁵	do.	1,430	23,310	1,810	27,176	1,730	20,635
Silver ²	metric tons	2,007	354,973	2,125	329,329	1,848	240,041
Zinc ²	do.	275,883	499,103	515,355	847,485	517,804	602,426
Combined value of antimony, bauxite, manganiferous ore (5% to 35%), mercury, rare-earth metal concentrates, tin, titanium concentrates (ilmenite and rutile), tungsten, vanadium, zircon concentrates, and values indicated by symbol W		XX	233,783	XX	237,468	XX	143,298
Total metals ⁶		XX	11,863,000	XX	12,442,000	XX	10,950,000
INDUSTRIAL MINERALS (EXCLUDING FUELS)							
Abrasives ⁷	metric tons	1,257	189	3,734	231	2,205	161
Asbestos	do.	17,427	W	W	W	W	W
Barite	thousand metric tons	290	12,625	430	16,000	448	21,310
Boron minerals (B ₂ O ₃)	metric tons	1,114,007	429,806	1,093,919	436,176	1,240,158	442,531
Bromine ⁸	thousand kilograms	175,000	188,650	177,000	97,350	170,000	167,000
Cement:							
Masonry	thousand short tons	3,329	229,441	3,274	225,404	2,637	187,679
Portland	do.	74,202	3,592,255	75,596	3,683,400	68,722	3,343,223
Clays	metric tons	42,254,269	1,515,300	42,904,437	1,619,826	44,091,697	1,505,088
Diatomite	do.	617,164	136,754	631,062	137,982	609,652	139,857
Feldspar	do.	654,313	28,029	630,000	28,471	580,000	26,000
Fluorspar	do.	66,000	W	63,500	W	W	W
Garnet (abrasive)	do.	42,604	4,408	47,009	6,937	50,860	7,534
Gemstones		NA	42,901	NA	52,867	NA	84,386
Gypsum (crude)	thousand short tons	17,624	128,448	16,406	99,567	15,456	94,199
Helium (Grade-A)	million cubic meters	82	106,523	87	113,183	88	174,706
Iodine	kilograms	1,508,000	23,947	1,972,849	30,486	1,998,914	31,389
Lime	thousand short tons	17,152	852,113	17,452	901,549	17,270	890,482
Mica (scrap)	thousand metric tons	119	6,273	109	5,841	103	5,542
Peat	thousand short tons	775	17,636	795	19,200	777	17,887
Perlite	short tons	601,000	16,301	726,000	17,443	566,639	15,086
Phosphate rock	thousand metric tons	49,817	1,082,797	46,343	1,075,093	48,096	1,030,913
Potash (K ₂ O equivalent)	do.	1,595	271,515	1,716	303,337	1,709	304,500
Pumice	metric tons	424,000	8,213	442,848	10,687	401,376	9,190
Salt	thousand short tons	38,356	776,846	40,693	826,659	39,575	801,507

See footnotes at end of table.

TABLE 1—Continued
NONFUEL MINERAL PRODUCTION¹ IN THE UNITED STATES

Mineral	1989		1990		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	
INDUSTRIAL MINERALS (EXCLUDING FUELS)—Continued							
Sand and gravel:							
Construction	thousand short tons	*897,300	*\$3,249,100	910,600	\$3,249,400	*780,300	*\$2,805,500
Industrial	do.	29,205	410,200	28,406	436,200	25,600	390,477
Sodium compounds:							
Soda ash	thousand metric tons	8,995	764,146	9,156	836,188	9,005	835,577
Sodium sulfate (natural)	do.	340	31,104	349	33,748	354	30,903
Stone:²							
Crushed	thousand short tons	1,213,400	5,325,800	*1,222,000	*5,591,300	1,102,878	5,186,821
Dimension	short tons	1,206,995	208,311	*1,186,216	*209,691	1,133,992	195,259
Sulfur (Frasch)	thousand metric tons	3,780	378,712	3,676	335,189	3,119	271,598
Talc and pyrophyllite	metric tons	1,253,128	W	W	W	W	W
Tripoli	do.	105,229	2,537	94,389	3,188	88,642	3,271
Vermiculite	short tons	293,320	32,550	229,584	19,075	185,103	13,410
Combined value of apatite, brucite, calcium chloride (natural), emery, graphite (natural, 1989), helium (crude), kyanite, lithium minerals, magnesite, magnesium compounds, marl (greensand), olivine, pyrites, staurolite, wollastonite, and values indicated by symbol W							
		XX	*483,673	XX	473,453	XX	506,275
Total industrial minerals³		XX	20,357,000	XX	*20,895,000	XX	19,539,000
Grand total⁴		XX	*32,220,000	XX	*33,337,000	XX	30,489,000

*Estimated. †Revised. NA Not available. W Withheld to avoid disclosing company proprietary data; value included with "Combined value" data. XX Not applicable.

¹Production as measured by mine shipments, sales, or marketable production (including consumption by producers).

²Recoverable content of ores, etc.

³Content of ore and concentrate.

⁴Data series revised to exclude nonnickel ore.

⁵Revised due to the separation of palladium metal from platinum metal.

⁶Data may not add to totals shown because of rounding.

⁷Grindstones, pulpstones, and sharpening stones; excludes mill liners and grinding pebbles.

⁸Excludes abrasive stone and bituminous limestone and sandstone; all included elsewhere in table.

TABLE 2
TOTAL U.S. NONRENEWABLE ORGANIC MATERIALS PRODUCTION, BY QUANTITY AND VALUE¹

(Million metric tons, unless otherwise specified)

Category	1989		1990		1991 [*]	
	Quantity	Value (millions)	Quantity	Value (millions)	Quantity	Value (millions)
Asphalt and road oil	25.52	\$2,817	25.02	\$3,480	25.69	\$2,944
Lubricants, waxes, and miscellaneous products	12.78	1,499	12.51	1,863	12.10	1,506
Petrochemical industries	55.66	6,331	57.75	7,759	65.09	7,455
Petroleum coke and coal	11.47	900	13.05	1,291	13.07	1,058
Total²	105.43	11,548	108.33	14,394	115.95	12,964

^{*}Estimated.

¹Quantities valued at the fossil fuel prices given in the Department of Energy, Energy Information Administration, Annual Energy Review 1991, June 1992, p. 69.

²Data may not add to totals shown because of independent rounding.

NOTE.—Nonrenewable organic materials represent all nonfuel uses in physical structure applications. The petrochemical industries category includes feedstocks for the production of plastics, synthetic rubber, synthetic fibers, pesticides, coatings, solvents, fertilizers, and other petrochemicals.

TABLE 3¹
NONFUEL MINERALS PRODUCED IN THE UNITED STATES AND PRINCIPAL PRODUCING STATES IN 1991

Mineral	Principal producing States, in order of quantity	Other producing States
Abrasives ²	AR, WY, OH	
Antimony ³	ID	
Aplite	VA	
Asbestos	CA and VT	
Barite	NV, GA, MO, MT	IL.
Bauxite	AL and GA	
Beryllium concentrate	UT	
Boron minerals	CA	
Bromine ^o	AR	
Brucite	NV	
Calcium chloride (natural)	MI and CA	
Cement:		
Masonry	IN, MI, PA, SC	All other States except AK, CT, DE, LA, MA, MN, MS, NV, NH, NJ, NC, ND, OR, RI, VT, WI, WY.
Portland	CA, TX, PA, MI	All other States except CT, DE, LA, MA, MN, NH, NJ, NC, ND, RI, VT, WI.
Clays	GA, WY, CA, TN	All other States except AK, DE, HI, RI, VT, WI.
Copper ³	AZ, NM, UT, MT	CA, CO, ID, MI, MO, NV, OR, TN.
Diatomite	CA, NV, WA, OR	
Emery	OR	
Feldspar	NC, CA, OK, GA	CT, ID, SD.
Fluorspar	IL	
Garnet (abrasive)	IN and NY	
Gold ³	NV, CA, UT, MT	AK, AZ, CO, ID, NM, SC, SD, WA.
Graphite (natural)	(⁴)	
Gypsum (crude)	MI, OK, IA, NV	AR, AZ, CA, CO, IN, KS, LA, NM, NY, SD, TX, UT, VA, WA, WY.
Helium (crude and Grade-A)	KS, WY, TX, CO	NM.
Iodine	OK	
Iron ore (includes byproduct)	MN, MI, UT, MO	AZ, CA, MT, NM, SD, TX.
Iron oxide pigments (crude)	MO, GA, MI, VA	AZ.
Kyanite	VA	
Lead ³	MO, AK, ID, CO	AZ, MT, NM, NV, NY, TN, WA.
Lime	MO, PA, OH, KY	All other States except AK, CT, DE, FL, GA, HI, KS, ME, MD, MS, NH, NJ, NM, NY, NC, RI, SC, VT.
Lithium minerals	NC and NV	
Magnesite	NV	
Magnesium compounds	MI, CA, FL, UT	DE and TX.
Magnesium metal	TX, WA, UT	
Manganiferous ore	SC	
Marl (greensand)	NJ	
Mercury	NV and CA	
Mica (scrap)	NC, NM, GA, SC	CA, CT, PA, SD.
Molybdenum	CA, AZ, UT, MT	CA, ID, NM, NV.
Nickel ore	OR	
Olivine	WA and NC	
Palladium metal	MT	
Peat	MI, FL, MN, IL	CO, IA, IN, MA, ME, MT, NC, NJ, NY, OH, PA, SC, WA, WI, WV.

See footnotes at end of table.

TABLE 3¹—Continued

NONFUEL MINERALS PRODUCED IN THE UNITED STATES AND PRINCIPAL PRODUCING STATES IN 1991

Mineral	Principal producing States, in order of quantity	Other producing States
Perlite	NM, AZ, CA, ID	CO and NV.
Phosphate rock	FL, NC, ID, UT	MT.
Platinum metal	MT	
Potash	NM, UT, CA, MI	
Pumice	CA, OR, AZ, NM	ID and KS.
Pyrites (ore and concentrate)	AZ	
Rare-earth metal concentrates	CA and FL	
Salt	NY, LA, OH, MI	AL, AZ, CA, KS, NM, NV, OK, TX, UT, WV.
Sand and gravel:		
Construction	CA, OH, WA, TX	All other States.
Industrial	IL, CA, TX, NJ	All other States except AK, CT, DE, HI, IA, ME, NH, NM, ND, OR, SD, UT, VT, WY.
Silver ³	NV, ID, AK, MT	AZ, CA, CO, MI, MO, NM, NY, SC, SD, TN, UT, WA.
Sodium compounds:		
Soda ash	WY and CA	
Sodium sulfate (natural)	CA, TX, UT	
Staurolite	FL	
Stone:		
Crushed	PA, IL, VA, FL	All other States except DE.
Dimension	VT, IN, SD, GA	All other States except AK, DE, FL, HI, KY, LA, MS, NE, NV, NJ, ND, OR, RI, UT, WV, WY.
Sulfur (Frasch)	TX and LA	
Talc and pyrophyllite	MT, NY, TX, VT	AL, CA, NC, OR, VA.
Tin	AK	
Titanium concentrates	FL, NJ, CA	
Tripoli	IL, AR, OK, PA	
Tungsten ³	CA	
Vanadium ³	ID	
Vermiculite (crude)	SC, VA, MT	
Wollastonite	NY	
Zinc ³	AK, TN, NY, MO	CO, ID, IL, MT, NM, NV, OR, WA.
Zircon concentrates	FL and NJ	

¹Estimated.²This table had been table 2 in previous issues of the Minerals Yearbook.³Grindstones, pulpstones, and sharpening stones; excludes mill liners and grinding pebbles.⁴Content of ores, etc.⁵No production reported.

TABLE 4¹
**VALUE OF NONFUEL MINERAL PRODUCTION IN THE UNITED STATES AND
 PRINCIPAL NONFUEL MINERALS PRODUCED IN 1991**

State	Value (thousands)	Rank	Percent of U.S. total	Principal minerals, in order of value
Alabama	\$539,915	20	1.77	Cement (portland), stone (crushed and broken), lime, sand and gravel (construction).
Alaska	494,064	21	1.62	Zinc, lead, sand and gravel (construction), gold.
Arizona	2,829,123	1	9.28	Copper, sand and gravel (construction), molybdenum, cement (portland).
Arkansas	360,984	26	1.18	Bromine, stone (crushed and broken), sand and gravel (construction), cement (portland).
California	2,532,043	2	8.30	Cement (portland), sand and gravel (construction), boron minerals, gold.
Colorado	338,405	31	1.11	Sand and gravel (construction), molybdenum, cement (portland), stone (crushed and broken).
Connecticut	90,833	43	.30	Stone (crushed and broken), sand and gravel (construction, industrial), feldspar.
Delaware ²	5,101	50	.02	Sand and gravel (construction) and gemstones.
Florida	1,396,164	5	4.58	Phosphate rock, stone (crushed and broken), cement (portland), sand and gravel (construction).
Georgia	1,298,621	6	4.26	Clays, stone (crushed and broken), cement (portland), stone (dimension).
Hawaii ²	141,112	39	.46	Stone (crushed and broken), cement (portland), sand and gravel (construction), cement (masonry).
Idaho	297,048	33	.97	Phosphate rock, silver, gold, sand and gravel (construction).
Illinois	673,291	16	2.21	Stone (crushed and broken), cement (portland), sand and gravel (construction, industrial).
Indiana	403,295	24	1.32	Stone (crushed and broken), cement (portland), sand and gravel (construction), stone (dimension).
Iowa	344,032	29	1.13	Stone (crushed and broken), cement (portland), sand and gravel (construction), gypsum (crude).
Kansas	365,679	25	1.20	Helium (crude and Grade-A), salt, stone (crushed and broken), cement (portland).
Kentucky	343,124	30	1.13	Stone (crushed and broken), lime, cement (portland), sand and gravel (construction).
Louisiana	351,802	27	1.15	Salt, sulfur (Frasch), sand and gravel (construction), stone (crushed and broken).
Maine	41,304	46	.14	Cement (portland), sand and gravel (construction), stone (crushed and broken), cement (masonry).
Maryland	348,212	28	1.14	Stone (crushed and broken), cement (portland), sand and gravel (construction), cement (masonry).
Massachusetts	111,597	41	.37	Stone (crushed and broken), sand and gravel (construction), stone (dimension), lime.
Michigan	1,503,268	4	4.93	Iron ore (usable), cement (portland), magnesium compounds, sand and gravel (construction).
Minnesota	1,288,885	7	4.23	Iron ore (usable), sand and gravel (construction), stone (crushed and broken), sand and gravel (industrial).
Mississippi	101,859	42	.33	Clays, sand and gravel (construction), cement (portland), stone (crushed and broken).
Missouri	880,352	12	2.89	Lead, cement (portland), stone (crushed and broken), lime.
Montana	590,297	17	1.94	Gold, copper, cement (portland), silver.
Nebraska	89,392	44	.29	Cement (portland), sand and gravel (construction), stone (crushed and broken), lime.
Nevada	2,392,901	3	7.85	Gold, silver, sand and gravel (construction), diatomite.
New Hampshire ²	30,392	47	.10	Sand and gravel (construction), stone (crushed and broken, dimension), and gemstones.
New Jersey	204,988	37	.67	Stone (crushed and broken), sand and gravel (construction, industrial), zircon concentrates.
New Mexico	985,563	10	3.23	Copper, potash, sand and gravel (construction), molybdenum.

See footnotes at end of table.

TABLE 4¹—Continued
**VALUE OF NONFUEL MINERAL PRODUCTION IN THE UNITED STATES AND
 PRINCIPAL NONFUEL MINERALS PRODUCED IN 1991**

State	Value (thousands)	Rank	Percent of U.S. total	Principal minerals, in order of value
New York	\$698,659	14	2.29	Stone (crushed and broken), salt, cement (portland), sand and gravel (construction).
North Carolina	552,898	18	1.81	Stone (crushed and broken), phosphate rock, lithium minerals, sand and gravel (construction).
North Dakota ²	17,366	48	.06	Sand and gravel (construction), lime, gemstones.
Ohio	683,585	15	2.24	Stone (crushed and broken), sand and gravel (construction), salt, lime.
Oklahoma	275,525	35	.90	Stone (crushed and broken), cement (portland), iodine (crude), sand and gravel (construction).
Oregon	197,928	38	.65	Stone (crushed and broken), sand and gravel (construction), cement (portland), lime.
Pennsylvania	844,001	13	2.77	Stone (crushed and broken), cement (portland), lime, sand and gravel (construction).
Rhode Island ²	13,263	49	.04	Stone (crushed and broken), sand and gravel (construction), gemstones.
South Carolina	338,145	32	1.11	Cement (portland), stone (crushed and broken), gold, clays.
South Dakota	289,922	34	.95	Gold, cement (portland), sand and gravel (construction), stone (crushed and broken).
Tennessee	547,787	19	1.80	Stone (crushed and broken), zinc, cement (portland), clays.
Texas	1,264,661	8	4.15	Cement (portland), stone (crushed and broken), magnesium metal, sulfur (Frasch).
Utah	1,149,067	9	3.78	Copper, gold, magnesium metal, cement (portland).
Vermont	59,820	45	.20	Stone (dimension, crushed and broken), sand and gravel (construction), talc and pyrophyllite.
Virginia	428,045	23	1.40	Stone (crushed and broken), lime, cement (portland), sand and gravel (construction).
Washington	482,659	22	1.58	Sand and gravel (construction), gold, magnesium metal, stone (crushed and broken).
West Virginia	116,931	40	.38	Stone (crushed and broken), cement (portland), sand and gravel (industrial, construction).
Wisconsin	213,849	36	.70	Stone (crushed and broken), sand and gravel (construction), lime, sand and gravel (industrial).
Wyoming	929,176	11	3.05	Soda ash, clays, helium (Grade-A), cement (portland).
Undistributed	7,386	—	—	
Total ³	30,489,000	XX	100.00	

XX Not applicable.

¹This table had been table 3 in previous issues of the Minerals Yearbook.

²Partial total, excludes values that must be concealed to avoid disclosing company proprietary data. Concealed values included with "Undistributed."

³Data may not add to totals shown because of rounding.

TABLE 5'
VALUE OF NONFUEL MINERAL PRODUCTION PER CAPITA AND PER SQUARE MILE IN 1991, BY STATE

State	Area (square miles)	Population (thousands)	Total value (thousands)	Per square mile		Per capita	
				Dollars	Rank	Dollars	Rank
Alabama	51,705	4,089	\$539,915	10,442	25	132	16
Alaska	591,004	570	494,064	836	49	867	3
Arizona	114,000	3,750	2,829,123	24,817	4	754	4
Arkansas	53,187	2,372	360,984	6,787	31	152	14
California	158,706	30,380	2,532,043	15,954	12	83	27
Colorado	104,091	3,377	338,405	3,251	43	100	22
Connecticut	5,018	3,291	90,833	18,101	10	28	44
Delaware	2,044	680	2/5,10	2,496	44	8	50
Florida	58,664	13,277	1,396,164	23,799	5	105	21
Georgia	58,910	6,623	1,298,621	22,044	6	196	11
Hawaii	6,471	1,135	2/141,11	21,807	7	124	17
Idaho	83,564	1,039	297,048	3,555	41	286	10
Illinois	56,345	11,543	673,291	11,949	19	58	38
Indiana	36,185	5,610	403,295	11,145	20	72	31
Iowa	56,275	2,795	344,032	6,113	33	123	18
Kansas	82,277	2,495	365,679	4,444	36	147	15
Kentucky	40,409	3,713	343,124	8,491	27	92	25
Louisiana	47,751	4,252	351,802	7,367	29	83	28
Maine	33,265	1,235	41,304	1,242	47	33	43
Maryland	10,460	4,860	348,212	33,290	1	72	32
Massachusetts	8,284	5,996	111,597	13,471	16	19	48
Michigan	58,527	9,368	1,503,268	25,685	3	160	13
Minnesota	84,402	4,432	1,288,885	15,271	13	291	9
Mississippi	47,689	2,592	101,859	2,136	45	39	41
Missouri	69,697	5,158	880,352	12,631	18	171	12
Montana	147,046	808	590,297	4,014	37	731	5
Nebraska	77,355	1,593	89,392	1,156	48	56	39
Nevada	110,561	1,284	2,392,901	21,643	8	1,864	2
New Hampshire	9,279	1,105	230,392	3,275	42	28	45
New Jersey	7,787	7,760	204,988	26,324	2	26	47
New Mexico	121,593	1,548	985,563	8,105	28	637	7
New York	49,107	18,058	698,659	14,227	14	39	42
North Carolina	52,669	6,737	552,898	10,498	24	82	29
North Dakota	70,703	635	217,366	246	50	27	46
Ohio	41,330	10,939	683,585	16,540	11	62	37
Oklahoma	69,956	3,175	275,525	3,939	38	87	26
Oregon	97,073	2,922	197,928	2,039	46	68	35
Pennsylvania	45,308	11,961	844,001	18,628	9	71	33
Rhode Island	1,212	1,004	213,263	10,943	21	13	49
South Carolina	31,113	3,560	338,145	10,868	22	95	24
South Dakota	77,116	703	289,922	3,760	40	412	8
Tennessee	42,144	4,953	547,787	12,998	17	111	19
Texas	266,807	17,349	1,264,661	4,740	35	73	30
Utah	84,899	1,770	1,153,751	13,590	15	652	6
Vermont	9,614	567	59,820	6,222	32	106	20
Virginia	40,767	6,286	428,045	10,500	23	68	34
Washington	68,138	5,018	482,659	7,084	30	96	23

See footnotes at end of table.

TABLE 5¹—Continued
VALUE OF NONFUEL MINERAL PRODUCTION PER CAPITA AND PER SQUARE MILE IN 1991, BY STATE

State	Area (square miles)	Population (thousands)	Total value (thousands)	Per square mile		Per capita	
				Dollars	Rank	Dollars	Rank
West Virginia	24,231	1,801	\$16,931	4,826	34	65	36
Wisconsin	56,153	4,955	213,849	3,808	39	43	40
Wyoming	97,809	460	929,176	9,500	26	2,020	1
Undistributed	XX	XX	7,386	XX	XX	XX	XX
Total ^{3,4} or average	3,618,700	251,583	30,489,000	8,425	XX	121	XX

XX Not applicable.

¹This table had been table 4 in previous issues of the Minerals Yearbook.

²Partial total, excludes values that must be concealed to avoid disclosing company proprietary data. Concealed values included with "Undistributed."

³Excludes Washington, DC (which has no mineral production), with an area of 69 square miles and a population of 598,000.

⁴Data may not add to totals shown because of rounding.

Sources: U.S. Bureau of Mines and Bureau of the Census.

TABLE 6¹
NONFUEL MINERAL PRODUCTION² IN THE UNITED STATES, BY STATE

Mineral	1989		1990		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	
ALABAMA							
Cement:							
Masonry	thousand short tons	252	\$13,852	262	\$15,462	*238	*\$14,042
Portland	do.	3,169	130,590	3,585	165,344	*3,937	*181,102
Clays ³	metric tons	1,878,070	18,537	2,049,776	27,747	2,124,380	22,103
Lime	thousand short tons	1,481	70,361	1,526	70,816	1,510	75,506
Sand and gravel:							
Construction	do.	*10,400	*36,500	14,103	50,243	*12,700	*45,700
Industrial	do.	805	8,092	878	9,075	531	6,133
Stone:							
Crushed and broken ⁴	do.	31,737	167,332	*36,100	*202,400	27,145	161,843
Dimension	short tons	W	W	W	W	9,552	2,449
Combined value of bauxite, clays [bentonite, kaolin (1990-91)], gemstones, salt, stone [crushed dolomite and granite (1991), crushed granite (1989-90)], talc and pyrophyllite, zircon concentrates, (1989), and values indicated by symbol W							
		XX	15,489	XX	*19,493	XX	31,037
Total		XX	460,753	XX	*560,580	XX	539,915
ALASKA							
Gemstones		NA	W	NA	W	NA	5
Gold ⁵	kilograms	5,756	70,800	3,232	40,200	3,196	37,331
Sand and gravel (construction)	thousand short tons	*17,000	*48,500	15,100	41,800	*14,000	*39,200
Stone (crushed)	do.	2,900	20,300	*2,700	*19,800	*1,085	*4,688
Combined value of cement (portland), lead, silver, stone [crushed sandstone (1991)], tin, zinc, and values indicated by symbol W							
		XX	73,752	XX	*474,781	XX	412,840
Total		XX	213,352	XX	*576,581	XX	494,064
ARIZONA							
Clays	metric tons	188,211	2,506	140,162	2,318	228,411	3,830
Copper ⁶	do.	898,466	2,593,734	978,767	2,657,649	1,024,066	2,468,255
Gemstones		NA	2,821	NA	2,098	NA	3,173
Gold ⁵	kilograms	2,768	34,047	5,000	62,191	2,068	24,159
Iron oxide pigments (crude)	metric tons	W	W	W	W	18	22
Sand and gravel (construction)	thousand short tons	*33,900	*133,900	27,915	92,166	*22,500	*79,400
Silver ⁷	metric tons	171	30,186	173	26,836	148	19,212
Stone (crushed)	thousand short tons	6,649	28,552	*5,300	*13,500	7,060	32,842
Combined value of cement, diatomite (1989-90), gypsum (crude), iron ore (usable, 1991), lead (1989, 1991), lime, molybdenum, perlite, pumice (1990-91), pyrites, salt, sand and gravel (industrial), stone (dimension), tin (1989), and values indicated by symbol W							
		XX	220,594	XX	*207,591	XX	198,230
Total		XX	3,046,340	XX	*3,064,349	XX	2,829,123

See footnotes at end of table.

TABLE 6¹—Continued
NONFUEL MINERAL PRODUCTION² IN THE UNITED STATES, BY STATE

Mineral	1989		1990		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	
ARKANSAS							
Abrasives ⁶	metric tons	W	W	W	W	\$154	
Bromine ⁹	thousand kilograms	W	W	177,000	\$97,350	170,000	167,000
Clays	metric tons	871,313	\$17,391	989,383	21,578	³ 856,582	³ 8,048
Gemstones		NA	4,041	NA	1,503	NA	1,846
Sand and gravel:							
Construction	thousand short tons	*7,500	*25,500	9,663	35,475	*8,300	*31,100
Industrial	do.	545	5,507	742	7,209	746	7,738
Stone:							
Crushed ⁴	do.	18,791	76,419	*17,800	*76,900	22,140	101,427
Dimension	short tons	W	W	W	W	13,932	1,128
Combined value of bauxite (1989-90), cement, clays (fire, 1991), gypsum (crude), lime, stone [crushed dolomite and traprock (1991), crushed slate and dolomite (1989-90)], talc and pyrophyllite (1989-90), tripoli, vanadium (1989-90), and values indicated by symbol W							
		XX	253,051	XX	62,625	XX	42,543
Total		XX	381,909	XX	302,640	XX	360,984
CALIFORNIA							
Boron minerals	metric tons	562,311	429,806	1,093,919	436,176	1,240,158	442,531
Cement (portland)	thousand short tons	10,911	642,020	10,032	604,080	*8,702	*522,120
Clays	metric tons	2,195,830	39,243	² 2,163,515	³ 40,217	² 2,074,707	² 27,464
Gemstones		NA	2,982	NA	1,501	NA	10,450
Gold ⁵	kilograms	29,804	366,595	29,607	368,300	29,873	348,919
Gypsum (crude)	thousand short tons	1,734	13,066	W	W	W	W
Lime	do.	395	24,503	345	19,425	307	20,389
Mercury	metric tons	W	W	(⁷)	(⁷)	(⁷)	1
Pumice	do.	79,000	4,612	71,739	5,088	61,237	4,372
Rare-earth metal concentrates	do.	W	W	W	W	16,465	W
Sand and gravel:							
Construction	thousand short tons	*138,300	*670,800	132,214	626,000	*101,900	*489,100
Industrial	do.	2,426	43,863	2,452	48,055	2,104	41,690
Silver ⁵	metric tons	21	3,650	21	3,209	W	W
Stone:							
Crushed	thousand short tons	54,887	238,034	*42,500	*200,600	45,816	216,156
Dimension	short tons	28,829	5,564	*30,077	*5,213	44,757	5,254
Combined value of asbestos, barite (1990), calcium chloride (natural), cement (masonry), clay [fuller's earth, (1990-91)], copper, diatomite, feldspar, iron ore [byproduct material (1989), usable], magnesium compounds, mica (crude, 1991), molybdenum, perlite, potash, salt, soda ash, sodium sulfate (natural), talc and pyrophyllite, titanium concentrates (ilmenite), tungsten ore concentrates, and values indicated by symbol W							
		XX	369,664	XX	*421,820	XX	403,597
Total		XX	2,854,402	XX	*2,779,684	XX	2,532,043

See footnotes at end of table.

TABLE 6¹—Continued
NONFUEL MINERAL PRODUCTION² IN THE UNITED STATES, BY STATE

Mineral	1989		1990		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	
COLORADO							
Clays	metric tons	265,435	\$2,064	262,292	\$1,864	\$263,866	\$1,964
Gemstones		NA	240	NA	66	NA	287
Gold ⁵	kilograms	3,448	42,411	2,357	29,176	3,181	37,154
Peat	thousand short tons	W	412	W	W	W	396
Sand and gravel (construction)	do.	*25,300	*104,000	24,938	86,541	*26,400	*88,200
Silver ⁵	metric tons	W	W	23	3,557	20	2,565
Stone:							
Crushed	thousand short tons	*7,261	*32,435	*7,600	*36,100	8,401	41,022
Dimension	short tons	5,310	398	*8,490	*1,394	W	W
Combined value of cement, clay (bentonite, 1990-91), copper, gypsum (crude), helium (Grade-A, 1990-91), lead, lime, molybdenum, perlite, sand and gravel (industrial), stone (crushed traprock, 1989-90), vanadium (1989-90), zinc, and values indicated by symbol W							
		XX	275,765	XX	227,586	XX	166,817
Total		XX	457,725	XX	386,284	XX	338,405
CONNECTICUT							
Gemstones		NA	2	NA	2	NA	62
Sand and gravel (construction)	thousand short tons	*5,800	*24,700	8,542	37,943	*5,400	*24,800
Stone:							
Crushed ⁴	do.	11,480	78,734	*10,200	*70,600	5,873	52,701
Dimension	short tons	W	W	W	W	17,326	1,739
Combined value of clays (common), feldspar, mica (scrap, 1990-91), sand and gravel (industrial), stone [crushed dolomite and other (1991), crushed granite (1989-90)], and values indicated by symbol W							
		XX	9,780	XX	9,348	XX	11,531
Total		XX	113,216	XX	117,893	XX	90,833
DELAWARE							
Gemstones		NA	1	NA	1	NA	1
Sand and gravel (construction)	thousand short tons	*1,900	*6,200	2,184	6,967	*1,600	*5,100
Total ⁸		XX	6,201	XX	6,968	XX	5,101
FLORIDA							
Cement:							
Masonry	thousand short tons	477	31,231	442	27,777	*214	*13,482
Portland	do.	4,357	207,857	3,954	186,404	*3,023	*142,081
Clays	metric tons	*563,687	*46,941	*391,334	*39,625	363,253	39,150
Gemstones		NA	W	NA	W	NA	6
Peat	thousand short tons	235	4,515	252	4,381	244	3,991
Sand and gravel:							
Construction	do.	*17,900	*55,500	18,472	59,123	*16,000	*51,400
Industrial	do.	681	7,768	520	7,024	551	5,989
Stone (crushed)	do.	83,995	341,397	*74,000	*317,400	*59,132	*260,901
Combined value of clays (common), magnesium compounds, phosphate rock, rare-earth metal concentrates, staurolite, stone [crushed marl (1991)], titanium concentrates (ilmenite and rutile), zircon concentrates, and values indicated by symbol W							
		XX	913,054	XX	*924,788	XX	879,164
Total		XX	1,608,263	XX	*1,566,522	XX	1,396,164

See footnotes at end of table.

TABLE 6¹—Continued
NONFUEL MINERAL PRODUCTION² IN THE UNITED STATES, BY STATE

Mineral	1989		1990		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	
GEORGIA							
Clays	metric tons	9,768,312	\$1,004,954	9,855,248	\$1,060,539	9,518,026	\$949,737
Gemstones		NA	21	NA	20	NA	10
Sand and gravel:							
Construction	thousand short tons	*6,100	*18,900	5,158	16,644	*4,700	*14,500
Industrial	do.	537	7,013	W	W	W	W
Stone:							
Crushed	do.	50,417	262,805	*53,000	*317,300	*41,339	*222,900
Dimension ³	short tons	145,545	12,087	*147,068	*12,483	173,892	14,167
Combined value of barite, bauxite (1989, 1991), cement, feldspar, iron oxide pigments (crude), mica (scrap), peat (1989-90), stone [crushed marble (1991), dimension marble], talc and pyrophyllite, and values indicated by symbol W							
		XX	81,515	XX	88,138	XX	97,307
Total		XX	1,387,295	XX	1,495,124	XX	1,298,621
HAWAII							
Cement:							
Masonry	thousand short tons	10	1,566	12	1,870	*10	*600
Portland	do.	493	40,495	532	46,311	*547	*47,589
Gemstones		NA	44	NA	55	NA	60
Sand and gravel (construction)	thousand short tons	*600	*3,200	438	2,459	*400	*2,300
Stone (crushed)	do.	6,205	46,746	*7,000	*55,400	*10,486	*90,563
Total ⁶		XX	92,051	XX	106,095	XX	141,112
IDAHO							
Clays ³	metric tons	W	W	W	W	967	W
Copper ⁵	do.	2,950	8,516	W	W	W	W
Feldspar	do.	11,612	720	W	W	W	W
Gemstones		NA	500	NA	320	NA	426
Gold ⁵	kilograms	3,057	37,602	W	W	3,348	39,107
Lime	thousand short tons	W	W	W	W	150	9,124
Phosphate rock	thousand metric tons	W	W	4,380	*67,978	5,921	86,328
Pumice	metric tons	W	W	31,333	220	36,868	267
Sand and gravel:							
Construction	thousand short tons	*5,800	*18,900	9,222	25,590	*11,600	*31,300
Industrial	do.	459	5,037	552	6,234	W	W
Silver ⁵	metric tons	439	77,651	*442	*68,418	337	43,807
Stone:							
Crushed	thousand short tons	3,298	12,609	*4,300	*12,900	3,230	15,057
Dimension	short tons	W	W	—	—	3,596	W
Combined value of antimony, cement, clays, [bentonite (1989), common, kaolin], garnet (abrasive), lead, molybdenum, perlite, vanadium ore, zinc, and values indicated by symbol W							
		XX	203,075	XX	*195,977	XX	71,632
Total		XX	364,610	XX	*377,637	XX	297,048

See footnotes at end of table.

TABLE 6¹—Continued
NONFUEL MINERAL PRODUCTION² IN THE UNITED STATES, BY STATE

Mineral	1989		1990		1991	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
ILLINOIS						
Cement (portland) thousand short tons	2,776	\$117,224	2,842	\$116,781	*2,654	*\$108,814
Clays ³ metric tons	142,207	641	598,479	2,516	935,154	38,877
Gemstones	NA	W	NA	W	NA	547
Sand and gravel:						
Construction thousand short tons	*33,000	*108,900	32,380	104,728	*26,300	*90,400
Industrial do.	4,582	52,935	4,486	62,531	4,146	57,210
Stone (crushed) ⁴ do.	60,829	256,832	*62,700	*283,100	68,586	295,362
Combined value of barite, cement (masonry), clays (fuller's earth 1989-90), copper (1989-90), fluorspar, lead (1989-90), lime, peat, silver (1989-90), stone [crushed sandstone (1989-91), and limestones (1991), dimension], tripoli, zinc, and values indicated by symbol W	XX	96,829	XX	95,478	XX	82,081
Total	XX	633,361	XX	665,134	XX	673,291
INDIANA						
Cement:						
Masonry thousand short tons	357	24,054	368	27,813	*317	*24,092
Portland do.	2,364	108,297	2,417	114,414	*2,252	*105,844
Clays metric tons	871,179	3,836	*1,051,703	*3,273	*929,964	*3,516
Gemstones	NA	W	NA	W	NA	561
Peat thousand short tons	34	607	37	W	26	W
Sand and gravel (construction) do.	*29,600	*99,200	23,879	76,886	*18,100	*60,400
Stone:						
Crushed do.	*36,188	*136,252	*36,700	*147,700	37,924	152,489
Dimension ⁴ short tons	198,531	27,212	*194,728	*29,504	187,580	27,491
Combined value of abrasives (1989), clays [ball (1990-91)], gypsum (crude), lime, sand and gravel (industrial), stone [crushed marl and miscellaneous stones (1989-90), dimension limestone and dolomite (1991), dimension sandstone (1989-90)], and values indicated by symbol W	XX	34,657	XX	32,176	XX	28,902
Total	XX	434,115	XX	431,766	XX	403,295
IOWA						
Cement:						
Masonry thousand short tons	47	4,450	53	5,054	*34	*3,264
Portland do.	2,072	102,387	2,525	122,466	*2,301	*112,749
Clays metric tons	439,323	1,773	423,227	1,376	530,477	2,226
Gemstones	NA	10	NA	14	NA	8
Gypsum (crude) thousand short tons	2,273	16,884	2,192	14,243	2,162	12,285
Sand and gravel (construction) do.	*12,800	*37,800	14,953	46,432	*17,400	*55,800
Stone:						
Crushed do.	28,049	111,182	*29,000	*118,600	*31,057	*147,815
Dimension short tons	15,151	613	W	W	W	W
Combined value of other industrial minerals and values indicated by symbol W	XX	7,603	XX	8,185	XX	9,885
Total	XX	282,702	XX	316,370	XX	344,032

See footnotes at end of table.

TABLE 6¹—Continued
NONFUEL MINERAL PRODUCTION² IN THE UNITED STATES, BY STATE

Mineral	1989		1990		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	
KANSAS							
Cement:							
Masonry	thousand short tons	42	\$2,514	39	\$2,011	*30	*\$1,530
Portland	do.	1,505	69,390	1,707	76,564	*1,466	*65,970
Clays ³	metric tons	533,099	2,700	625,969	4,056	607,419	2,828
Gemstones		NA	W	NA	W	NA	527
Helium (Grade-A)	million cubic meters	W	W	W	W	39	76,540
Salt ⁹	thousand short tons	1,948	82,212	2,390	92,119	2,316	97,713
Sand and gravel:							
Construction	do.	*13,000	*33,200	10,863	24,170	*9,600	*22,100
Industrial	do.	230	2,690	W	W	W	W
Stone:							
Crushed ⁴	do.	15,850	56,976	*20,800	*79,200	16,802	67,249
Dimension	short tons	W	W	W	W	19,651	2,171
Combined value of clay (bentonite, 1989), gypsum (crude), helium (crude), pumice, salt (brine), stone [crushed quartzite (1991), sandstone and quartzite (1989-90)], and values indicated by symbol W							
		XX	68,449	XX	67,999	XX	29,051
Total		XX	318,131	XX	346,119	XX	365,679
KENTUCKY							
Clays ³	metric tons	716,990	3,357	826,205	8,282	707,587	2,942
Gemstones		NA	W	NA	W	NA	548
Sand and gravel (construction)	thousand short tons	*5,500	*15,100	8,802	29,581	*7,700	*27,200
Stone (crushed)	do.	*48,178	*187,849	*50,100	*182,900	46,266	191,893
Combined value of cement, clays [ball fire (1989)], lead (1990), lime, sand and gravel (industrial), silver (1990), stone [crushed dolomite (1989-90)], zinc (1990), and values indicated by symbol W							
		XX	124,353	XX	138,101	XX	120,541
Total		XX	330,659	XX	358,864	XX	343,124
LOUISIANA							
Clays	metric tons	233,992	6,115	368,322	1,066	360,154	3,646
Gemstones		NA	14	NA	7	NA	27
Salt	thousand short tons	13,218	115,203	14,348	120,827	14,595	130,587
Sand and gravel:							
Construction	do.	*13,600	*54,400	14,589	55,902	*13,300	*48,900
Industrial	do.	572	9,664	559	10,003	W	W
Stone (crushed)	do.	3,206	24,414	*2,100	*16,800	W	W
Sulfur (Frasch)	thousand metric tons	1,334	W	1,337	W	1,063	W
Combined value of gypsum (crude), lime, stone [crushed miscellaneous (1991)], and values indicated by symbol W							
		XX	169,912	XX	163,313	XX	168,642
Total		XX	379,722	XX	367,918	XX	351,802

See footnotes at end of table.

TABLE 6¹—Continued
NONFUEL MINERAL PRODUCTION² IN THE UNITED STATES, BY STATE

Mineral	1989		1990		1991	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
MAINE						
Gemstones	NA	W	NA	W	NA	\$174
Sand and gravel (construction) thousand short tons	*\$8,600	*\$30,100	7,865	\$29,349	*3,900	*14,800
Stone:						
Crushed do.	1,591	8,801	*1,700	*8,700	1,706	9,899
Dimension short tons	W	W	W	W	73	88
Combined value of cement, clays (common), peat, and values indicated by symbol W	XX	25,753	XX	24,495	XX	16,343
Total	XX	64,654	XX	62,544	XX	41,304
MARYLAND						
Cement (portland) thousand short tons	1,871	94,002	1,798	91,172	*1,580	*80,580
Clays metric tons	351,464	1,882	338,775	1,712	*258,760	*1,141
Gemstones	NA	3	NA	3	NA	3
Peat do.	3	W	3	W	—	—
Sand and gravel (construction) do.	*16,900	*84,500	18,271	104,023	*13,000	*72,800
Stone:						
Crushed do.	30,841	153,375	*30,500	*163,900	25,545	188,001
Dimension short tons	27,529	2,072	*24,102	*1,751	12,090	967
Combined value of other industrial minerals and values indicated by symbol W	XX	6,216	XX	6,053	XX	4,720
Total	XX	342,050	XX	368,614	XX	348,212
MASSACHUSETTS						
Gemstones	NA	3	NA	1	NA	1
Sand and gravel:						
Construction thousand short tons	*13,900	*57,000	12,774	51,466	*10,100	*39,400
Industrial do.	34	601	30	401	30	401
Stone:						
Crushed do.	11,880	67,768	*9,200	*54,500	7,131	51,362
Dimension short tons	67,533	10,302	*56,254	*10,992	69,332	11,646
Combined value of clays (common), lime, and peat	XX	8,452	XX	10,138	XX	8,787
Total	XX	144,126	XX	127,498	XX	111,597
MICHIGAN						
Cement:						
Masonry thousand short tons	255	22,286	272	23,880	*225	*22,440
Portland do.	5,449	253,324	5,906	263,607	*4,935	*222,075
Clays metric tons	1,249,198	4,599	1,201,542	4,094	2,061,861	8,770
Gemstones	NA	10	NA	11	NA	10
Gypsum (crude) thousand short tons	2,089	15,589	2,000	11,511	1,721	13,052
Iron ore (usable) thousand metric tons	15,045	W	10,034	W	*12,662	W
Lime thousand short tons	621	32,479	622	30,898	613	30,959
Peat do.	286	6,082	280	6,264	249	6,442
Sand and gravel:						
Construction do.	*48,000	*132,000	53,729	153,057	*44,800	*132,200
Industrial do.	2,865	24,577	2,310	19,285	2,093	18,464
Stone (crushed) do.	40,905	123,678	*43,100	*129,000	40,989	129,490

See footnotes at end of table.

TABLE 6¹—Continued
NONFUEL MINERAL PRODUCTION² IN THE UNITED STATES, BY STATE

Mineral	1989		1990		1991	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
MICHIGAN—Continued						
Combined value of calcium chloride (natural), copper, gold (1989), iron oxide pigments (crude), magnesium compounds, potash, salt, silver, stone (dimension), and values indicated by symbol W	XX	\$84,347	XX	\$96,516	XX	\$19,366
Total	XX	1,598,971	XX	1,438,123	XX	1,503,268
MINNESOTA						
Gemstones	NA	42	NA	46	NA	62
Iron ore (usable) thousand metric tons	41,044	1,223,909	45,139	1,308,920	*42,966	*1,157,920
Peat thousand short tons	33	1,415	48	2,972	35	1,910
Sand and gravel (construction) do.	*33,700	*82,600	33,869	77,502	*24,500	*58,800
Stone:						
Crushed do.	8,760	30,218	*9,100	*31,900	8,378	30,624
Dimension short tons	44,605	16,031	*60,195	*20,836	45,795	13,962
Combined value of clays (common, kaolin), lime, and sand and gravel (industrial)	XX	22,022	XX	27,746	XX	25,607
Total	XX	1,376,237	XX	1,469,922	XX	1,503,268
MISSISSIPPI						
Clays ³ short tons	899,373	23,573	817,828	16,196	1,172,213	34,382
Gemstones	NA	5	NA	1	NA	1
Sand and gravel (construction) thousand short tons	*15,600	*51,500	13,032	45,817	*9,900	*33,000
Stone (crushed) do.	1,069	3,994	*1,400	*5,500	1,632	6,603
Combined value of cement [masonry (1989-90), portland], clays [ball, fuller's earth (1990), kaolin (1991)], and sand and gravel (industrial)	XX	28,539	XX	44,799	XX	27,873
Total	XX	107,611	XX	112,313	XX	101,859
MISSOURI						
Cement (portland) thousand short tons	4,922	182,005	4,481	180,090	*4,276	*171,040
Clays ³ metric tons	1,479,898	14,665	1,347,558	12,864	2,001,537	11,060
Iron ore (usable) thousand metric tons	1,060	W	1,002	W	*224	W
Lead ⁵ metric tons	366,931	318,320	*380,781	*386,345	351,995	259,841
Sand and gravel:						
Construction thousand short tons	*10,000	*32,500	9,243	25,097	*7,400	*20,100
Industrial do.	750	9,972	W	W	W	W
Silver ⁵ metric tons	53	9,456	*42	*6,434	35	4,483
Stone (crushed) thousand short tons	51,754	171,848	*53,100	*190,900	47,938	167,233
Zinc ⁵ metric tons	50,790	91,885	48,864	80,355	42,506	49,453
Combined value of barite, cement (masonry), clays (fuller's earth), copper, gemstones, iron oxide pigments (crude), lime, stone (dimension), and values indicated by symbol W	XX	219,236	XX	*220,555	XX	197,142
Total	XX	1,049,887	XX	*1,102,640	XX	880,352
MONTANA						
Clays metric tons	*95,743	*1,835	*29,741	*193	362,635	11,332
Gemstones	NA	2,500	NA	3,692	NA	2,796
Gold ⁵ kilograms	12,434	152,941	13,012	161,861	18,511	216,211
Palladium metal ¹⁰ do.	4,850	22,454	5,930	21,735	6,050	16,923
Platinum metal ¹¹ do.	1,430	23,310	1,810	*27,176	1,730	20,635
Sand and gravel (construction) thousand short tons	*5,800	*13,900	5,114	14,319	*4,800	*13,700

See footnotes at end of table.

TABLE 6¹—Continued
NONFUEL MINERAL PRODUCTION² IN THE UNITED STATES, BY STATE

Mineral	1989		1990		1991	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
MONTANA—Continued						
Silver ⁵ metric tons	194	\$4,367	220	\$4,114	222	\$8,893
Stone (crushed) thousand short tons	2,846	9,718	*4,000	*15,300	2,107	5,725
Talc and pyrophyllite metric tons	453,978	12,718	430,125	18,883	W	W
Combined value of barite, cement, clays [bentonite (1990), fire (1989)], copper, graphite [natural (1989)], gypsum (crude 1989), iron ore (usable), lead, lime, molybdenum, peat, phosphate rock, sand and gravel (industrial), stone (dimension), vermiculite, zinc, and values indicated by symbol W	XX	292,394	XX	*275,944	XX	274,082
Total	XX	566,137	XX	573,024	XX	590,297
NEBRASKA						
Clays metric tons	224,624	880	227,292	1,685	198,319	909
Gemstones	NA	2	NA	7	NA	1
Sand and gravel (construction) thousand short tons	*15,200	*41,800	11,453	30,056	*10,100	*27,300
Stone (crushed) do.	3,978	20,050	*4,000	*21,200	4,861	23,328
Combined value of cement, lime, and sand and gravel (industrial)	XX	41,085	XX	37,381	XX	37,854
Total	XX	103,817	XX	90,329	XX	89,392
NEVADA						
Barite thousand metric tons	209	3,473	337	5,884	374	11,933
Clays ³ metric tons	57,264	5,457	34,625	4,098	15,553	3,204
Gemstones	NA	1,402	NA	407	NA	958
Gold ⁵ kilograms	153,995	1,894,172	*179,078	*2,216,233	177,312	2,071,009
Lead ⁵ metric tons	—	—	830	842	W	W
Mercury do.	W	W	W	W	57	202
Perlite short tons	5,000	136	W	W	W	W
Sand and gravel:						
Construction thousand short tons	*20,000	*70,000	18,377	59,008	*20,300	*69,000
Industrial do.	718	W	607	W	546	W
Silver ⁵ metric tons	625	110,442	*646	*100,146	578	75,050
Stone (crushed) thousand short tons	1,560	4,638	*1,600	*5,000	1,199	6,527
Zinc ⁵ metric tons	—	—	7,889	12,973	W	W
Combined value of brucite, cement (portland), clays [fuller's earth (1990-91), kaolin], copper, diatomite, fluorspar (1989-90), gypsum (crude), lime, lithium minerals, magnesite, molybdenum, salt, and values indicated by symbol W	XX	220,441	XX	*216,820	XX	155,018
Total	XX	2,310,161	XX	*2,621,411	XX	2,392,901
NEW HAMPSHIRE						
Gemstones	NA	51	NA	38	NA	31
Sand and gravel (construction) thousand short tons	*6,000	*20,400	7,901	26,599	*4,700	*16,200
Stone:						
Crushed do.	771	4,020	*600	*2,500	1,542	9,148
Dimension short tons	55,305	8,769	*45,073	*6,029	34,803	5,013
Total ⁸	XX	33,240	XX	35,166	XX	30,392

See footnotes at end of table.

TABLE 6¹—Continued
NONFUEL MINERAL PRODUCTION² IN THE UNITED STATES, BY STATE

Mineral	1989		1990		1991	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
NEW JERSEY						
Clays ³ metric tons	18,492	\$400	W	W	W	W
Gemstones	NA	3	NA	\$3	NA	\$3
Peat thousand short tons	W	638	W	527	W	541
Sand and gravel:						
Construction do.	*15,200	*68,400	13,862	64,245	*10,300	*47,900
Industrial do.	1,797	26,138	1,762	26,190	1,634	23,738
Stone (crushed) do.	20,799	140,998	*21,200	*131,700	*16,680	*119,287
Zircon concentrates metric tons	W	8,988	W	W	W	W
Combined value of clays [common, fire (1990-91)], marl (greensand), stone [crushed sandstone and other (1991)], titanium concentrates [ilmenite and rutile (1991)], and values indicated by symbol W	XX	3,318	XX	6,805	XX	13,519
Total	XX	248,883	XX	229,470	XX	204,988
NEW MEXICO						
Clays metric tons	31,012	94	³ 27,994	³ 74	³ 27,794	³ 74
Copper ⁵ do.	259,640	749,540	262,815	713,622	252,859	609,454
Gemstones	NA	279	NA	225	NA	100
Gold ⁵ kilograms	1,076	13,231	888	11,041	W	W
Lead ⁵ metric tons	W	W	W	W	193	142
Perlite short tons	487,000	13,080	501,000	*13,181	W	W
Potash thousand metric tons	1,365	242,619	1,451	245,571	1,469	250,900
Pumice metric tons	77,000	795	W	W	W	W
Sand and gravel (construction) thousand short tons	*11,800	*45,400	10,362	39,708	*9,200	*35,900
Silver ⁵ metric tons	W	W	48	7,431	W	W
Stone (crushed) thousand short tons	2,784	11,672	*2,400	*12,800	2,801	13,089
Combined value of cement, clays [fire (1990-91)], gypsum (crude), helium (Grade-A), iron ore [includes byproduct material (1989-90), usable], mica (scrap), molybdenum, salt, stone (dimension), zinc, and values indicated by symbol W	XX	45,593	XX	*59,828	XX	75,904
Total	XX	1,122,303	XX	*1,103,481	XX	985,563
NEW YORK						
Clays metric tons	531,559	3,429	490,552	2,906	421,003	2,417
Gemstones	NA	350	NA	365	NA	125
Peat thousand short tons	W	10	W	W	1	21
Salt do.	5,424	161,427	5,401	162,900	4,998	173,837
Sand and gravel:						
Construction do.	*31,600	*118,500	29,750	121,525	*23,700	*95,500
Industrial do.	53	633	W	W	W	W
Stone:						
Crushed do.	39,851	201,749	*39,900	*207,600	34,871	195,639
Dimension short tons	23,756	3,575	*23,437	*3,589	18,624	2,978
Combined value of cement, garnet (abrasive), gypsum (crude), iron ore [includes byproduct material (1989)], lead, silver, talc and pyrophyllite, wollastonite, zinc, and values indicated by symbol W	XX	255,495	XX	273,954	XX	228,142
Total	XX	745,168	XX	772,839	XX	698,659

See footnotes at end of table.

TABLE 6¹—Continued
NONFUEL MINERAL PRODUCTION² IN THE UNITED STATES, BY STATE

Mineral	1989		1990		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	
NORTH CAROLINA							
Clays	metric tons	2,270,384	\$15,529	² 2,179,428	³ \$9,356	² 2,063,875	³ \$9,015
Feldspar	do.	435,845	14,024	418,402	¹ 14,460	402,448	13,027
Gemstones		NA	784	NA	1,057	NA	785
Mica (scrap)	thousand metric tons	73	4,192	65	3,796	64	3,747
Peat	thousand short tons	W	W	13	W	21	W
Sand and gravel:							
Construction	do.	¹ 11,200	⁴ 43,700	11,733	44,872	⁹ 9,900	³ 35,000
Industrial	do.	1,627	19,902	1,177	15,338	1,174	15,565
Stone:							
Crushed	do.	51,519	257,976	⁵ 52,900	² 276,200	⁴ 46,514	² 243,920
Dimension	short tons	62,665	10,477	⁶ 66,531	¹ 11,551	32,489	10,128
Combined value of clays [kaolin (1990-91)], lithium minerals, olivine, phosphate rock, stone [crushed volcanic cinder (1991)], talc and pyrophyllite, and values indicated by symbol W							
		XX	214,984	XX	² 213,112	XX	221,711
Total		XX	581,568	XX	⁵ 589,742	XX	552,898
NORTH DAKOTA							
Clays	metric tons	47,903	W	50,485	W	27,825	W
Gemstones		NA	10	NA	10	NA	6
Lime	thousand short tons	107	5,439	82	4,623	98	5,360
Sand and gravel (construction)	do.	³ 3,600	⁸ 8,100	7,644	17,219	⁵ 5,000	¹ 12,000
Stone (crushed)	short tons	—	—	¹ 1,000	⁴ 4,600	11	W
Combined value of other industrial minerals and values indicated by symbol W							
		XX	111	XX	116	XX	(¹²)
Total		XX	13,660	XX	26,568	XX	¹ 17,366
OHIO							
Cement:							
Masonry	thousand short tons	128	11,233	124	10,880	¹ 109	⁹ 9,591
Portland	do.	1,446	73,230	1,426	72,883	¹ 1,356	⁶ 9,156
Clays	metric tons	3,519,668	14,983	2,546,151	13,334	2,204,635	11,015
Gemstones		NA	18	NA	W	NA	57
Lime	thousand short tons	1,888	94,157	1,884	92,817	1,783	85,976
Peat	do.	8	182	12	182	9	222
Sand and gravel:							
Construction	do.	⁴ 44,400	¹ 148,700	44,552	165,394	⁴ 42,300	¹ 160,100
Industrial	do.	1,394	24,662	1,349	24,205	1,294	23,462
Stone:							
Crushed	do.	46,426	183,190	⁴ 48,400	¹ 190,900	⁴ 47,310	¹ 184,177
Dimension	short tons	59,923	3,455	⁶ 61,783	³ 3,468	⁴ 42,355	² 2,279
Combined value of abrasives, gypsum (crude), salt, stone [crushed limestone and dolomite (1991)], dimension limestone (1991)], and value indicated by symbol W							
		XX	145,346	XX	154,777	XX	137,550
Total		XX	699,156	XX	728,840	XX	683,585

See footnotes at end of table.

TABLE 6¹—Continued
NONFUEL MINERAL PRODUCTION² IN THE UNITED STATES, BY STATE

Mineral	1989		1990		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	
OKLAHOMA							
Cement (portland)	thousand short tons	1,236	\$39,360	1,544	\$60,457	*1,620	*\$63,180
Clays	metric tons	565,956	1,619	631,302	3,156	*824,176	*4,178
Gypsum (crude)	thousand short tons	2,523	14,369	2,184	11,154	2,356	12,925
Iodine (crude)	kilograms	1,505,714	23,947	1,972,849	30,486	1,998,914	31,389
Sand and gravel:							
Construction	thousand short tons	*8,500	*20,000	9,235	21,993	*9,000	*22,300
Industrial	do.	1,216	18,310	1,258	22,984	1,241	20,918
Stone:							
Crushed ⁴	do.	23,598	81,969	*25,300	*89,500	25,678	95,509
Dimension	short tons	8,290	762	*8,138	*684	*3,836	*596
Tripoli	metric tons	W	W	18,801	155	15,885	141
Combined value of cement (masonry), feldspar, gemstones, lime, salt (1990-91), stone [crushed dolomite, dimension sandstone (1991)], and values indicated by symbol W							
		XX	18,695	XX	19,608	XX	24,389
Total		XX	219,031	XX	260,177	XX	275,525
OREGON							
Cement (portland)	thousand short tons	W	W	W	W	*249	*18,675
Clays	metric tons	210,893	875	223,452	1,390	213,356	1,086
Gemstones		NA	1,304	NA	1,683	NA	2,758
Nickel ore ¹³	metric tons	NA	NA	330	NA	5,523	NA
Sand and gravel (construction)	thousand short tons	*14,400	*49,700	15,785	60,928	*15,600	*62,800
Stone (crushed) ⁴	do.	18,407	81,204	*18,000	*86,600	20,608	89,322
Talc and pyrophyllite	metric tons	204	18	105	10	63	67
Zinc ⁵	do.	—	—	—	—	751	873
Combined value of cement [masonry (1989-90)], copper (1991), diatomite, emery, gold (1989-90), lime, pumice, silver (1989-90), stone [crushed dolomite and quartzite (1989-90), crushed slate (1991)], value indicated by symbol W							
		XX	49,965	XX	*53,984	XX	22,347
Total		XX	183,066	XX	204,595	XX	197,928
PENNSYLVANIA							
Cement:							
Masonry	thousand short tons	349	26,473	303	22,594	*253	*18,975
Portland	do.	5,757	301,980	5,621	286,185	*4,881	*248,931
Clays ³	metric tons	1,049,973	4,936	840,646	2,900	701,399	2,890
Gemstones		NA	5	NA	5	NA	5
Lime	thousand short tons	1,660	92,139	1,626	92,557	1,695	95,328
Peat	do.	20	746	18	730	10	207
Sand and gravel (construction)	do.	*19,500	*94,600	20,883	97,348	*18,300	*87,800
Stone:							
Crushed ⁴	do.	93,123	455,004	*95,800	*502,700	70,334	362,306
Dimension	short tons	44,267	10,032	*43,952	*9,898	38,493	10,077
Combined value of clays [fire (1990), kaolin], mica (scrap), sand and gravel (industrial), stone [crushed granite (1989-90), crushed limestone, dolomite, and quartzite (1991)], and tripoli							
		XX	14,754	XX	15,125	XX	17,482
Total		XX	1,000,669	XX	1,030,042	XX	844,001

See footnotes at end of table.

TABLE 6¹—Continued
NONFUEL MINERAL PRODUCTION² IN THE UNITED STATES, BY STATE

Mineral	1989		1990		1991	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
RHODE ISLAND						
Gemstones	NA	\$2	NA	\$2	NA	\$1
Sand and gravel (construction) thousand short tons	*1,100	*3,900	1,969	9,042	*1,300	*6,000
Stone (crushed) do.	¹⁴ 1,208	7,170	* ¹⁴ 1,600	*8,800	1,187	7,262
Total ⁸	XX	11,072	XX	17,844	XX	13,263
SOUTH CAROLINA						
Cement (portland) thousand short tons	2,188	99,083	2,464	109,644	*2,215	*99,675
Clays metric tons	1,596,153	39,075	2,062,824	44,486	1,709,205	25,662
Gemstones	NA	10	NA	10	NA	10
Sand and gravel:						
Construction thousand short tons	*7,500	*23,300	8,627	24,941	*6,600	*18,900
Industrial do.	842	16,635	844	15,972	822	16,348
Stone:						
Crushed ⁴ do.	24,429	111,656	*26,200	*135,400	18,216	84,260
Dimension short tons	W	W	W	W	8,829	854
Combined value of cement (masonry), gold, manganiferous ore, mica (scrap), peat, silver, stone [crushed shell (1989-90), crushed dolomite (1991)], vermiculite, and values indicated by symbol W	XX	135,538	XX	119,400	XX	92,436
Total	XX	425,297	XX	449,853	XX	338,145
SOUTH DAKOTA						
Gemstones	NA	150	NA	110	NA	W
Gold ⁵ kilograms	16,123	198,318	*17,870	*221,157	16,371	191,217
Lead ⁵ metric tons	4	3	—	—	—	—
Sand and gravel (construction) thousand short tons	*6,400	*20,800	9,689	23,689	*8,700	*20,800
Silver ⁵ metric tons	4	705	*10	*1,566	7	944
Stone:						
Crushed thousand short tons	3,833	14,303	*4,800	*16,800	4,824	19,657
Dimension short tons	54,623	17,738	*50,688	*12,871	W	W
Combined value of cement, clays (common), feldspar, gypsum (crude), iron ore (usable), lime, mica (scrap), and values indicated by symbol W	XX	32,341	XX	34,310	XX	57,304
Total	XX	284,358	XX	*310,503	XX	289,922
TENNESSEE						
Clays ³ metric tons	1,137,152	\$26,292	1,060,662	\$25,776	828,635	\$44,572
Sand and gravel (construction) thousand short tons	*6,100	*21,900	7,619	23,474	*6,700	*21,100
Stone:						
Crushed do.	52,917	252,785	*54,600	*268,600	44,088	223,561
Dimension short tons	4,888	437	*10,108	*2,051	3,460	260
Combined value of barite (1989), cement, clays [common (1989,1991), fuller's earth], copper, gemstones, lead, lime, phosphate rock (1989-90), sand and gravel (industrial), silver, and zinc	XX	336,993	XX	*344,627	XX	258,294
Total	XX	638,407	XX	*664,528	XX	547,787

See footnotes at end of table.

TABLE 6¹—Continued
NONFUEL MINERAL PRODUCTION² IN THE UNITED STATES, BY STATE

Mineral	1989		1990		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	
TEXAS							
Cement:							
Masonry	thousand short tons	133	\$10,735	142	\$10,106	W	W
Portland	do.	7,200	286,236	7,678	296,680	*7,498	*\$289,341
Clays ³	metric tons	2,276,629	15,962	2,162,095	14,652	2,265,746	13,247
Gypsum (crude)	thousand short tons	1,993	17,044	1,868	10,166	1,609	9,240
Lime	do.	1,304	60,829	1,337	76,181	1,373	69,400
Salt	do.	7,856	69,934	8,212	75,149	8,935	73,117
Sand and gravel:							
Construction	do.	*43,900	*155,800	46,083	158,080	*38,800	*135,800
Industrial	do.	1,661	29,107	1,849	40,880	1,557	27,002
Stone:							
Crushed	do.	76,823	252,982	*81,800	*285,700	65,813	226,836
Dimension	short tons	81,268	12,449	*84,500	*12,600	W	W
Sulfur (Frasch)	thousand metric tons	2,446	W	2,340	W	2,056	W
Talc and pyrophyllite	metric tons	241,777	4,564	227,138	4,844	212,887	4,561
Combined value of clays [ball (1989, 1991), bentonite (1990-91), fuller's earth (1990-91), kaolin], gemstones, helium (crude and Grade-A), iron ore (usable), magnesium compounds, magnesium metal, sodium sulfate (natural), and values indicated by symbol W							
		XX	546,812	XX	472,187	XX	416,117
Total		XX	1,462,454	XX	1,457,225	XX	1,264,661
UTAH							
Beryllium concentrates	metric tons	4,592	5	4,548	5	7,339	5
Clays	do.	321,949	2,633	³ 277,795	¹ 1,774	² 210,382	¹ 1,028
Gemstones		NA	659	NA	713	NA	489
Lime	thousand short tons	373	17,974	354	18,878	325	18,634
Salt	do.	1,183	40,421	1,171	50,436	1,326	29,959
Sand and gravel:							
Construction	do.	*14,300	*41,500	13,601	44,881	*14,400	*48,200
Industrial	do.	3	60	2	42	—	—
Silver ⁵	metric tons	W	W	147	22,750	W	W
Stone (crushed)	thousand short tons	4,683	19,176	*4,600	*20,200	4,450	18,259
Combined value of cement, clays [bentonite (1990-91)], copper, fluorspar (1990), gold, gypsum (crude), iron ore (usable), magnesium compounds, magnesium metal, mercury (1989-90), molybdenum, phosphate rock, potash, sodium sulfate (natural), vanadium ore (1989-90), and values indicated by symbol W							
		XX	1,168,065	XX	*1,174,213	XX	1,037,177
Total		XX	1,290,493	XX	1,333,892	XX	1,153,751

See footnotes at end of table.

TABLE 6¹—Continued
NONFUEL MINERAL PRODUCTION² IN THE UNITED STATES, BY STATE

Mineral	1989		1990		1991	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
VERMONT						
Gemstones	NA	\$10	NA	\$10	NA	\$5
Sand and gravel (construction) thousand short tons	*6,900	*20,400	3,675	11,948	*3,000	*9,900
Stone:						
Crushed do.	3,119	28,110	*3,700	*35,000	2,685	12,666
Dimension short tons	100,698	31,413	*99,243	*28,950	92,676	31,013
Combined value of other industrial minerals	XX	8,969	XX	6,046	XX	6,236
Total	XX	88,902	XX	81,954	XX	59,820
VIRGINIA						
Clays ³ metric tons	1,001,394	6,302	882,383	3,741	723,495	3,248
Gemstones	NA	27	NA	34	NA	70
Lime thousand short tons	821	38,353	846	39,784	825	39,612
Sand and gravel (construction) do.	*12,900	*49,700	13,096	48,950	*9,700	*36,900
Stone:						
Crushed do.	64,061	328,050	*59,400	*320,000	48,861	260,966
Dimension short tons	W	W	W	W	11,046	3,061
Combined value of aplite, cement, clays (fuller's earth), gypsum (crude), iron oxide pigments (crude), kyanite, sand and gravel (industrial), talc and pyrophyllite, vermiculite, and values indicated by symbol W	XX	86,669	XX	94,766	XX	84,188
Total	XX	509,101	XX	507,275	XX	428,045
WASHINGTON						
Clays metric tons	233,267	1,591	158,257	1,357	263,374	2,633
Gemstones	NA	208	NA	281	NA	85
Gold ⁵ kilograms	W	W	9,620	119,671	9,954	116,260
Sand and gravel (construction) thousand short tons	*37,800	*124,700	40,251	133,067	40,200	140,700
Stone (crushed) do.	13,259	55,624	*12,700	*41,900	13,126	59,588
Combined value of cement, diatomite, gypsum (crude), lead (1991), lime, magnesium metal, olivine, peat, sand and gravel (industrial), silver, stone (dimension), zinc (1991), and value indicated by symbol W	XX	298,756	XX	176,953	XX	163,393
Total	XX	480,879	XX	473,229	XX	482,659
WEST VIRGINIA						
Clays metric tons	251,385	553	164,257	384	134,262	322
Gemstones	NA	1	NA	1	NA	2
Sand and gravel (construction) thousand short tons	*2,300	*6,700	3,208	14,950	*3,100	*14,300
Stone (crushed) do.	*10,904	*42,538	*12,000	*45,200	10,255	50,505
Combined value of cement, lime, peat (1990-91), salt, sand and gravel (industrial), and stone (crushed granite, 1989-90)	XX	75,706	XX	75,803	XX	51,802
Total	XX	125,498	XX	136,338	XX	116,931

See footnotes at end of table.

TABLE 6¹—Continued
NONFUEL MINERAL PRODUCTION² IN THE UNITED STATES, BY STATE

Mineral	1989		1990		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	
WISCONSIN							
Gemstones	NA	W	NA	W	NA	\$542	
Lime	thousand short tons	437	\$18,129	461	\$24,608	536	23,225
Peat	do.	13	309	12	256	9	227
Sand and gravel:							
Construction	do.	*21,700	*56,400	29,572	73,750	*29,600	*77,500
Industrial	do.	1,514	22,399	W	W	W	W
Stone:							
Crushed	do.	26,520	83,664	*26,600	*91,000	*23,676	*80,475
Dimension	short tons	35,587	4,376	*31,316	*3,811	*37,470	*4,347
Combined value of other industrial minerals and value indicated by symbol W							
		XX	(¹²)	XX	18,622	XX	27,533
Total		XX	*185,277	XX	212,047	XX	213,849
WYOMING							
Clays ³	metric tons	2,166,497	74,697	2,523,573	76,082	2,496,361	81,573
Gemstones		NA	157	NA	151	NA	61
Lime	thousand short tons	W	W	W	W	37	2,729
Sand and gravel (construction)	do.	*4,500	*15,400	4,329	14,446	*3,500	*11,900
Stone (crushed)	do.	2,990	12,120	*2,200	*14,000	2,946	12,645
Combined value of cement [masonry (1989-90), portland], clays (common), gypsum (crude), helium (Grade-A), soda ash, and values indicated by symbol W							
		XX	724,987	XX	806,169	XX	820,268
Total		XX	827,361	XX	910,848	XX	929,176
UNDISTRIBUTED							
Delaware, Hawaii, New Hampshire, North Dakota (1991), Rhode Island, Wisconsin (1989), and Undistributed (1989, 1991)							
		XX	9,043	XX	5,938	XX	7,386

¹Estimated. ²Revised. NA Not available. W Withheld to avoid disclosing company proprietary data, value included with "Combined value." XX Not applicable.

³This table had been table 5 in previous issues of the Minerals Yearbook.

⁴Production as measured by mine shipments, sales, or marketable production (including consumption by producers).

⁵Excludes certain clays; kind and value included with "Combined value."

⁶Excludes certain stones; kind and value included with "Combined value."

⁷Recoverable content of ores, etc.

⁸Grindstones, pulpstones, and sharpening stones; excludes mill liners and grinding pebbles.

⁹Less than 1/2 unit.

¹⁰Partial total, excludes values that must be concealed to avoid disclosing company proprietary data. Values excluded from partial total included with "Undistributed States."

¹¹Excludes salt in brines; value included with "Combined value."

¹²Palladium metal separated from platinum-group metals in 1990: 1989 data revised.

¹³Platinum metal separated from platinum-group metals in 1990: 1989 data revised.

¹⁴Value excluded to avoid disclosing company proprietary data.

¹⁵Data series revised to exclude nonnickel ore.

¹⁶Excludes traprock.

TABLE 7¹
**NONFUEL MINERAL PRODUCTION² IN THE COMMONWEALTH OF PUERTO RICO AND ISLANDS
ADMINISTERED BY THE UNITED STATES**

Mineral	1989		1990		1991	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
PUERTO RICO						
Cement (portland) thousand short tons	1,374	\$112,318	1,486	\$122,027	*1,382	*\$110,560
Clays metric tons	136,873	311	W	W	145,483	355
Lime thousand short tons	26	3,800	29	3,483	30	4,440
Sand and gravel (industrial) do.	30	600	55	825	55	825
Stone (crushed) do.	8,389	46,648	NA	NA	8,828	49,839
Total	XX	163,677	XX	³ 126,335	XX	166,019
ADMINISTERED ISLANDS						
American Samoa: Stone (crushed) thousand short tons	48	476	—	—	69	756
Guam: Stone (crushed) do.	1,063	11,133	—	—	2,201	18,038
Virgin Islands : Stone (crushed) do.	312	3,159	—	—	W	W
Total	XX	14,768	XX	—	XX	18,794

¹Estimated. NA Not available. W Withheld to avoid disclosing company proprietary data; not included in "Total." XX Not applicable.

²This table is a compilation of previous Minerals Yearbook tables 6 and 7.

³Production as measured by mine shipments, sales, or marketable production (including consumption by producers).

*Total does not include value of item withheld.

TABLE 8
U.S. EXPORTS OF PRINCIPAL MINERALS AND PRODUCTS, EXCLUDING MINERAL FUELS

Mineral	1990 ^r		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	
METALS					
Aluminum:					
Aluminum oxide (alumina)	thousand metric tons	1,263	\$425,712	1,351	\$408,367
Crude and semicrude	metric tons	1,659,124	3,294,938	1,762,287	3,356,065
Manufactures	do.	1,696,203	3,429,659	1,824,468	3,557,070
Speciality compounds (aluminum sulfate, aluminum oxide abrasives, and various fluorine-base compounds)	do.	20,722	19,428	39,200	45,630
Antimony:					
Metal, alloys, waste and scrap	do.	588	1,143	694	1,138
Oxide (antimony content)	do.	7,142	13,962	3,752	7,404
Bauxite (dried and calcined)	thousand metric tons	74	12,644	44	9,148
Beryllium [alloys (wrought or unwrought), and waste and scrap]	kilograms	45,227	4,831	33,122	2,690
Bismuth metal (alloys, waste and scrap)	do.	121,677	878	74,597	641
Cadmium metal (alloys, dross, flue dust, residues, and scrap)	metric tons	385	1,174	158	218
Chromium:					
Chemicals	do.	22,500	26,449	23,237	30,514
Chromite ore and concentrate	do.	6,321	1,488	8,759	2,041
Metal and alloys	do.	9,456	13,984	11,073	16,398
Pigments	do.	2,643	9,252	1,969	7,423
Cobalt:					
Metal (unwrought, powders, waste and scrap, and mattes and other intermediate metallurgy products)	do.	543	8,880	543	13,963
Metal (wrought and cobalt articles)	do.	481	12,300	323	13,400
Ores and concentrates	do.	49	416	9	231
Oxides and hydroxides	do.	922	6,776	1,102	10,623
Other forms (acetates and chlorides)	do.	542	2,477	822	5,866
Columbium:					
Ferrocolumbium	thousand kilograms	585	5,495	741	6,952
Ores and concentrates	do.	48	337	8	55
Copper:					
Scrap (alloy and unalloyed)	metric tons	324,390	520,141	306,593	446,363
Semimanufactures [bare wire (includes wire rod), bars, cable foil, oxides, hydroxides, pipes, plates, sheets, tubing, and wire (stranded)]	do.	68,519	278,528	77,438	306,873
Sulfate	do.	559	NA	827	2,361
Unmanufactures (ash, anodes, blister, concentrates, matte, ore, precipitates, refined, and unalloyed scrap, copper content)	do.	647,154	1,239,714	679,654	1,215,720
Gold:					
Bullion (refined)	kilograms	140,923	1,719,470	174,377	2,038,850
Doré and precipitates	do.	88,203	413,980	45,536	486,266
Ores and concentrates	do.	328	3,721	10	98
Wastes and scrap	do.	66,943	729,150	64,204	653,748
Indium	do.	NA	NA	NA	NA
Iron ore:					
Ore and agglomerates	thousand metric tons	3,199	124,076	4,045	156,242
Iron and steel:					
Cast iron and steel products	do.	172	315,114	165	338,944
Direct-reduced iron	do.	63	38,103	22	33,845
Fabricated steel products	do.	578	1,580,893	645	1,742,491

See footnotes at end of table.

TABLE 8—Continued
U.S. EXPORTS OF PRINCIPAL MINERALS AND PRODUCTS, EXCLUDING MINERAL FUELS

Mineral	1990 ^a		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	
METALS—Continued					
Iron and steel—Continued:					
Ferrous alloys not elsewhere listed:					
Ferrophosphorous	metric tons	5,981	\$2,344	2,872	\$1,822
Ferrozirconium	do.	88	74	95	138
Ferrous alloys (n.e.c.)	do.	3,893	5,229	2,800	4,112
Pig iron	thousand metric tons	14	1,618	15	1,700
Steel mill products	do.	3,904	2,768,712	5,757	3,671,704
Iron and steel scrap [includes mixed rails (new and used) for rolling and other uses, and ships, boats, and other vessels for scrapping]	do.	11,657	1,657,884	9,514	1,257,388
Lead:					
Ash and residues (lead content)	metric tons	12,765	8,096	11,828	4,106
Ore and concentrate (lead content)	do.	56,600	33,369	87,953	25,159
Scrap	do.	75,507	33,934	93,262	26,574
Unwrought metal and alloys (lead content)	do.	57,226	59,080	94,428	69,982
Wrought metal and alloys (lead content)	do.	6,759	19,923	7,615	20,614
Magnesium:					
Alloys	do.	4,633	16,050	3,233	10,132
Metal	do.	41,882	124,714	42,859	119,848
Powder, sheets, tubing, ribbons, wire, and other forms and other forms	do.	4,352	21,127	8,149	18,046
Waste and scrap	do.	967	2,522	919	2,304
Manganese:					
Ferromanganese (all grades)	short tons	8,302	6,565	16,064	15,414
Metal (alloys, waste, and scrap)	do.	6,773	14,043	5,811	12,658
Ore and concentrates	do.	77,101	9,297	73,074	8,523
Silicomanganese	do.	1,974	1,666	3,167	2,802
Mercury metal	metric tons	311	2,440	786	3,144
Molybdenum (molybdenum content):					
Ferromolybdenum	do.	300	2,372	375	3,058
Ore and concentrates	do.	41,380	169,888	33,424	113,709
Oxides and hydroxides	do.	787	5,095	1,571	9,678
Molybdates (all)	do.	680	3,963	740	3,965
Powder	do.	292	4,565	230	4,907
Unwrought	do.	180	2,453	88	1,204
Wire	do.	338	12,863	360	12,053
Wrought	do.	190	7,595	110	5,570
Nickel (nickel content):					
Unwrought					
Primary [anodes (electroplating), briquets, cathodes, chemicals (catalysts and salts), ferrouckel, flakes, oxide sinter, pellets, powder, and shot]	do.	8,873	77,047	9,104	91,359
Secondary (stainless steel and scrap)	do.	37,057	338,770	36,902	334,764
Wrought (bars, foil, pipes, profiles, rods, sheets, strips, tubes, and wire)	do.	465	5,937	354	5,756
Platinum-group metals (iridium, osmium, palladium, platinum, rhodium, ruthenium, and waste and scrap)	kilograms	55,044	415,605	39,624	461,588
Rare-earth metals (rare-earth oxide content):					
Cerium compounds	do.	1,729,771	9,983	1,368,535	8,195
Compounds (inorganic and organic)	do.	2,085,214	18,010	1,793,092	20,954
Ferrocium and pyrophoric alloys	do.	2,033,217	8,685	2,099,616	9,343

See footnotes at end of table.

TABLE 8—Continued
U.S. EXPORTS OF PRINCIPAL MINERALS AND PRODUCTS, EXCLUDING MINERAL FUELS

Mineral	1990 ^a		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	
METALS—Continued					
Rare-earth metals (rare-earth oxide content)—Continued:					
Metals (includes scandium and yttrium)	kilograms	201,122	\$1,249	59,035	\$2,683
Ores and concentrates	metric tons	NA	NA	459	NA
Selenium (metal, waste and scrap, selenium content)	kilograms	194,608	1,283	210,495	1,939
Silicon:					
Ferrosilicon	metric tons	50,079	43,993	50,393	43,008
Metal	do.	8,980	92,229	8,246	112,323
Silver:					
Bullion (refined)	kilograms	735,993	119,892	787,474	115,224
Doré and precipitates	do.	13,184	2,353	53,128	8,486
Ores and concentrates	do.	21,861	3,994	299	49
Waste and scrap	do.	1,077,421	159,194	840,229	124,015
Tantalum:					
Ores and concentrates (includes synthetic)	thousand kilograms	14	138	11	248
Unwrought (alloys, metal, powders, and waste and scrap)	waste and scrap do.	183	29,200	208	27,646
Wrought	do.	60	20,068	77	26,580
Thorium:					
Compounds	kilograms	220	68	2,649	154
Tin:					
Ingots and pigs	metric tons	658	3,344	970	5,455
Tin scrap and other tin-bearing material, except tinplate scrap, (includes bars, rods, profiles, wire, powders, flakes, tubes, and pipes)	do.	106,389	55,921	121,359	88,327
Tinplate and terneplate	do.	145,396	78,687	150,187	89,677
Titanium:					
Metal:					
Scrap	do.	5,487	22,443	4,568	10,706
Sponge	do.	331	2,073	418	2,604
Other unwrought (billet, blooms and sheet bars, ingots, etc.)	do.	5,472	69,235	3,845	47,833
Wrought (bars, rods, etc.)	do.	4,526	148,290	3,300	113,060
Ores and concentrates	do.	18,765	7,398	26,912	10,167
Pigments (dioxides and oxides)	do.	202,288	434,560	189,679	349,516
Tungsten (tungsten content):					
Ammonium paratungstate	do.	356	2,456	770	4,114
Carbide powder	do.	1,074	21,946	839	18,880
Metal and alloy powder	do.	988	18,587	689	13,947
Miscellaneous tungsten-bearing materials [ferrotungsten and ferrosilicon tungsten, unwrought, wire (metal and alloy), wrought, other compounds (other tungstates), and other metal]	do.	795	36,683	822	40,037
Ore and concentrate	do.	139	765	21	165
Vanadium:					
Aluminum-vanadium master alloy	kilograms	381,595	7,468	170,392	4,344
Compounds [pentoxide (includes catalysts), and other (excludes vanadates), vanadium content]	do.	2,437,934	16,166	1,810,150	10,957
Ferrovandium	do.	334,272	5,480	178,027	2,454

See footnotes at end of table.

TABLE 8—Continued
U.S. EXPORTS OF PRINCIPAL MINERALS AND PRODUCTS, EXCLUDING MINERAL FUELS

Mineral	1990 ^a		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	
METALS—Continued					
Zinc:					
Blocks, pigs, anodes, etc. (unwrought and unwrought alloys)	metric tons	5,804	\$11,304	5,477	\$8,680
Compounds	do.	8,089	39,182	9,659	42,346
Dust and flakes	do.	8,701	17,039	5,737	8,247
Ore and concentrate	do.	220,446	188,686	381,416	221,948
Oxide	do.	7,141	10,032	6,653	8,756
Waste and scrap (zinc content)	do.	109,316	85,749	96,314	61,706
Wrought zinc and zinc alloys (angles, bars, pipes, plates, rods, strips, etc.)	do.	15,612	18,541	16,536	22,466
Zirconium:					
Ore and concentrates	do.	30,195	21,101	31,333	20,607
Unwrought waste and scrap	do.	188	3,057	238	5,785
Total metals ¹		XX	21,926,000	XX	22,955,000
INDUSTRIAL MINERALS					
Abrasive materials (includes reexports):					
Natural		XX	144,613	XX	158,518
Manufactured		XX	150,860	XX	161,433
Asbestos (includes reexports):					
Manufactured		XX	120,328	XX	116,015
Unmanufactured	metric tons	27,965	7,964	25,636	7,424
Barite: Natural barium sulfate	do.	9,227	1,675	43,296	3,304
Boron:					
Boric acid	thousand metric tons	39	31,679	47	35,457
Sodium borates	do.	585	208,433	554	205,722
Bromine:					
Compounds (contained bromine)	thousand kilograms	14,443	18,166	14,555	21,280
Elemental	do.	2,932	4,008	2,563	7,665
Calcium chloride	metric tons	23,300	6,591	30,568	8,030
Cement: Hydraulic and clinker	thousand short tons	554	38,306	697	45,773
Clays and clay products	thousand metric tons	4,123	584,404	3,997	590,174
Diatomite	do.	144	42,329	152	45,187
Feldspar	do.	24,795	2,167	8,425	1,334
Fluorspar	do.	14,921	1,891	73,943	16,424
Gemstones (includes reexports):					
Diamonds (excludes industrial diamond)	thousand carats	1,215,420	1,432,600	1,839,583	1,382,700
Graphite:					
Artificial (includes artificial, and colloidal or semicolloidal) ³	metric tons	33,085	31,625	37,662	29,876
Natural (amorphous, crystalline flake, lump or chip, and natural n.e.c.)	do.	11,537	9,481	19,374	11,345
Gypsum:					
Boards	thousand short tons	69	30,959	105	36,943
Crude	do.	129	5,056	74	3,720
Plasters	do.	94	18,381	96	19,872
Other	do.	XX	30,056	XX	25,077
Helium (Grade-A)	million cubic meters	25	33,450	27	36,504
Iodine:					
Crude	thousand kilograms	NA	NA	1,358	15,784
Potassium iodide	do.	NA	NA	105	398

See footnotes at end of table.

TABLE 8—Continued
U.S. EXPORTS OF PRINCIPAL MINERALS AND PRODUCTS, EXCLUDING MINERAL FUELS

Mineral	1990 ^a		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	
INDUSTRIAL MINERALS—Continued					
Iron oxide pigments:					
Pigment grade	metric tons	9,535	\$18,694	20,606	\$33,816
Other grade	do.	199,470	111,081	164,084	109,463
Lime	short tons	44,287	4,755	41,975	4,659
Lithium compounds:					
Lithium carbonate	kilograms	9,312,903	30,160	9,564,674	31,273
Lithium hydroxide	do.	3,147,248	12,953	3,078,922	12,998
Lithium metal	do.	111,737	NA	57,373	NA
Magnesium:					
Calcined dolomite	metric tons	10,379	2,213	16,702	3,349
Caustic-calcined magnesia	do.	2,313	1,406	3,640	2,289
Compounds (chlorides, hydroxide and peroxide, and sulfates)	do.	14,162	14,165	8,913	8,022
Dead-burned and fused magnesia	do.	58,610	19,709	66,292	25,038
Magnesite (crude)	do.	8,009	8,060	7,961	5,567
Other magnesia	do.	37,747	16,108	25,149	13,985
Mica:					
Scrap and flake:					
Powder	do.	4,319	2,050	3,420	1,717
Waste	do.	580	646	874	331
Sheet:					
Unworked	do.	148	272	205	309
Worked	do.	612	7,568	411	7,454
Nitrogen compounds (major):					
Anhydrous ammonia	thousand short tons	522	NA	603	NA
Fertilizer materials	do.	13,032	NA	15,177	NA
Industrial chemicals	do.	89	126,658	149	110,131
Perlite (crude)	short tons	*35,000	*956	*32,000	*852
Phosphorus:					
Diammonium and monoammonium phosphates	thousand metric tons	8,493	1,414,219	10,505	1,847,926
Elemental phosphorous	metric tons	17,916	29,620	17,018	30,421
Phosphate rock:					
Ground	thousand metric tons	1,084	38,695	219	13,078
Unground	do.	5,875	215,409	5,530	246,755
Phosphoric acid	do.	555	95,881	440	76,342
Superphosphates	do.	747	100,630	946	125,989
Potash:					
Potassium chloride, all grades	metric tons	445,800	46,500	730,600	NA
Potassium sulfate	do.	243,700	43,300	203,300	NA
Potassium magnesium sulfate	do.	318,200	41,400	306,400	NA
Potassium nitrate	do.	7,841	5,000	15,910	NA
Pumice and pumicite	thousand metric tons	20	483	13	290
Quartz crystal:					
Cultured	thousand kilograms	39	1,745	53	2,620
Natural	do.	NA	NA	NA	NA
Salt	thousand short tons	2,498	32,944	1,959	29,875

See footnotes at end of table.

TABLE 8—Continued
U.S. EXPORTS OF PRINCIPAL MINERALS AND PRODUCTS, EXCLUDING MINERAL FUELS

Mineral	1990 ^r		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	
INDUSTRIAL MINERALS—Continued					
Sand and gravel:					
Construction:					
Gravel	thousand short tons	NA	NA	700	\$6,043
Sand	do.	468	\$11,880	439	1,301
Industrial	do.	1,155	83,826	1,637	106,606
Sodium compounds:					
Soda ash	thousand metric tons	2,392	346,693	2,734	409,088
Sodium sulfate	do.	62	6,704	103	11,495
Stone:					
Crushed	thousand short tons	5,100	41,400	2,415	33,003
Dimension		NA	54,019	NA	64,947
Strontium compounds (precipitated carbonate, oxide, hydroxide, and peroxide)	kilograms	2,882,105	2,298	1,800,221	1,765
Sulfur:					
Elemental	thousand metric tons	972	109,327	1,196	119,713
Sulfuric acid (100% H ₂ SO ₄)	metric tons	161,509	11,515	148,872	11,806
Talc (excludes talcum in packages, face, and compact)	thousand metric tons	238	32,909	178	30,050
Vermiculite	thousand short tons	20	NA	11	NA
Total industrial minerals¹		XX	6,099,000	XX	6,526,000
Total¹		XX	28,025,000	XX	29,481,000

^rEstimated. ^rRevised. NA Not available. XX Not applicable.

¹Data may not add to totals shown because of rounding.

²Artificial graphite includes large amounts of materials made from petroleum coke.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF PRINCIPAL MINERALS AND PRODUCTS,
EXCLUDING MINERAL FUELS

Mineral	1990 ^a		1991	
	Quantity	Value (thousands)	Quantity	Value (thousands)
METALS				
Aluminum:				
Aluminum oxide (alumina) thousand metric tons	4,069	\$1,268,973	4,592	\$1,102,008
Crude and semicrude metric tons	1,514,147	2,699,773	1,489,600	2,268,296
Manufactures do.	1,559,503	2,854,340	1,532,886	2,411,269
Antimony:				
Metal do.	13,940	23,380	13,502	23,841
Ore and concentrate (antimony content) do.	3,454	4,835	3,381	5,250
Oxides (antimony content) do.	12,012	19,574	11,950	18,941
Arsenic:				
Acid do.	21	31	374	427
Metal do.	796	4,091	1,008	2,899
Sulfides do.	—	—	(¹)	31
Trioxide do.	26,256	12,570	27,142	14,320
Bauxite:				
Calcined thousand metric tons	558	37,205	376	25,198
Crude and dried do.	12,142	NA	11,793	NA
Beryllium:				
Beryl metric tons	342	418	288	394
Metal and compounds kilograms	111,185	1,031	118,343	822
Bismuth metals and alloys do.	1,611,862	11,747	1,411,394	7,876
Cadmium metal metric tons	1,741	11,904	2,039	7,928
Chromium:				
Chemicals do.	10,130	24,136	11,987	10,875
Chromite do.	305,506	22,150	212,139	14,963
Metals and alloys do.	426,358	292,216	411,602	278,897
Pigments and preparations based chromium do.	5,652	13,708	4,939	13,453
Cobalt:				
Metal (unwrought, unwrought alloys, waste and scrap, mattes and other intermediate metallurgy products) do.	6,342	111,106	6,844	165,227
Metal (wrought and cobalt articles) do.	48	3,729	105	5,503
Oxide and hydroxides do.	488	8,539	583	12,941
Other forms (sulfates, chlorides, carbonates and acetates) do.	547	3,227	448	3,482
Columbium:				
Ferrocolumbium thousand kilograms	2,919	24,685	3,282	27,415
Ores and concentrates do.	2,251	7,898	2,515	8,445
Oxide do.	973	15,348	603	10,210
Unwrought (alloys, metals, and powders) do.	2	149	1	103
Copper:				
Scrap (alloy and unalloyed) metric tons	134,614	273,753	125,928	216,305
Semimanufactures [bare wire (includes wire rod), bars, cable (stranded), foil, hydroxides, oxides, pipes, plates, tubing, sheets, and wire (stranded)] do.	87,562	361,477	69,467	294,825

See footnotes at end of table.

TABLE 9—Continued
**U.S. IMPORTS FOR CONSUMPTION OF PRINCIPAL MINERALS AND PRODUCTS,
 EXCLUDING MINERAL FUELS**

Mineral	1990 ^a		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	
METALS—Continued					
Copper—Continued:					
Unmanufactures (anode, ash, blister, concentrates, matte, ore, precipitates, refined, and scrap [unalloyed], copper content)	metric tons	441,308	\$1,030,828	442,027	\$962,387
Gallium	kilograms	9,894	3,250	11,271	3,829
Germanium materials	do.	49,789	27,971	26,834	11,999
Gold:					
Bullion (refined)	do.	64,755	795,007	147,491	1,721,576
Doré and precipitates	do.	4,245	50,635	5,597	66,735
Ore and concentrates	do.	5,346	8,355	992	10,874
Wastes and scrap	do.	23,173	206,975	24,668	126,264
Hafnium (unwrought waste and scrap)	metric tons	9	1,662	3	489
Indium (unwrought waste and scrap)	kilograms	30,158	6,555	36,288	7,867
Iron ore:					
Ore and agglomerates	thousand metric tons	18,054	559,525	13,335	436,777
Pellets	do.	9,875	355,470	9,317	338,493
Iron and steel:					
Cast iron and steel products	do.	215	212,769	187	195,644
Direct-reduced iron	do.	385	87,469	423	97,897
Fabricated steel products	do.	2,016	3,054,601	1,709	2,705,856
Ferroalloys not elsewhere listed:					
Ferrophosphorus	metric tons	237	526	6,713	1,835
Ferrotitanium and ferrosilicon-titanium	do.	1,960	9,202	1,166	3,819
Ferrozirconium	do.	—	—	288	483
Ferroalloys (n.e.c.)	do.	2,404	8,351	16,485	24,749
Pig iron	thousand metric tons	347	60,069	434	75,261
Steel mill products	do.	15,575	8,344,593	14,280	9,060,231
Iron and steel scrap (includes used rail for rerolling and other uses)	do.	1,464	196,658	1,166	158,725
Lead:					
Base bullion (lead content)	metric tons	2,713	1,636	419	283
Miscellaneous products (lead content)	do.	515	6,782	1,154	4,133
Ore and concentrates (lead content)	do.	10,668	5,167	12,437	4,466
Pigments and compounds	do.	23,082	33,110	23,946	29,967
Pigs and bars (lead content)	do.	90,638	74,395	116,473	69,351
Reclaimed scrap (includes ash and residues, lead content) dues, lead content)	do.	281	102	117	28
Wrought (all forms, including wire and powders, gross weight)	do.	6,723	9,944	5,792	8,460
Magnesium:					
Waste and scrap	do.	4,075	8,137	4,150	4,653
Metal	do.	16,139	47,025	21,758	52,186
Alloys (magnesium content)	do.	5,344	20,726	4,596	15,903
Powders, sheets, tubing, ribbons, wire, and other forms (magnesium content)	do.	1,197	4,420	1,359	4,866

See footnotes at end of table.

TABLE 9—Continued
**U.S. IMPORTS FOR CONSUMPTION OF PRINCIPAL MINERALS AND PRODUCTS,
 EXCLUDING MINERAL FUELS**

Mineral	1990 ^a		1991	
	Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued				
Manganese:				
Chemicals (manganese dioxide and potassium permanganate) short tons	9,806	\$12,453	23,138	\$30,724
Metal do.	14,279	19,741	17,407	24,509
Ore and concentrates (manganese content) do.	328,360	80,108	258,504	80,664
Ferromanganese (all grades, manganese content) do.	656,704	468,658	552,198	378,324
Silicomanganese (manganese content) do.	163,075	117,847	187,155	130,677
Mercury (metal, mercury-bearing waste and scrap) metric tons	15	231	56	301
Molybdenum (molybdenum content):				
Ferromolybdenum do.	871	6,990	953	7,304
Ore and concentrates do.	478	3,184	161	882
Oxides and hydroxides (gross weight) do.	643	3,569	948	5,013
Molybdates (all) do.	63	627	77	772
Powder do.	71	1,771	28	821
Unwrought do.	39	2,147	45	1,596
Wire (gross weight) do.	3	249	2	211
Wrought (gross weight) do.	61	4,217	53	3,275
Other (inorganic compounds, orange, waste and scrap, and other, gross weight) do.	1,133	5,268	1,186	6,237
Nickel (nickel content):				
Unwrought				
Primary [briquets, cathodes, chemicals (catalysts and salts), ferronickel, flakes, oxide sinter, pellets, powder, and shot] do.	131,116	1,177,634	132,445	1,123,536
Secondary (stainless steel scrap and waste and scrap) do.	142,749	1,255,682	138,657	1,182,174
Wrought (bars, foil, pipes, profiles, rods, sheets, strips, tubes, and wire) do.	1,035	15,495	1,131	16,880
Platinum-group metals (iridium, osmium, palladium, platinum, rhodium, ruthenium, ores, and waste and scrap) kilograms	125,354	1,905,830	125,661	1,742,866
Rare-earth metals (rare-earth oxide content):				
Cerium compounds (includes chlorides, hydroxides, nitrates, oxides, oxilate, and sulfates) do.	359,230	2,040	544,962	4,913
Compounds (includes hydroxides, nitrates, oxides, and others, except chlorides) do.	4,989,646	37,325	3,693,163	34,079
Chloride mixtures (except cerium chloride) do.	1,362,951	12,813	3,377,242	8,890
Ferrocerium and other pyrophoric alloys do.	93,130	1,495	92,997	1,424,071
Monazite metric tons	440	686	—	—
Oxide mixtures (except cerium oxides) kilograms	150,728	8,018	892,277	13,138
Rare-earth metals (whether intermixed or alloyed) do.	198,840	3,050	225,820	3,329
Rhenium:				
Ammonium perrhenate do.	3,002	2,127	3,513	2,815
Metal do.	5,888	6,864	10,847	13,316

^a See footnotes at end of table.

TABLE 9—Continued
**U.S. IMPORTS FOR CONSUMPTION OF PRINCIPAL MINERALS AND PRODUCTS,
 EXCLUDING MINERAL FUELS**

Mineral	1990 ^a		1991	
	Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued				
Selenium:				
Selenium dioxide (selenium content) kilograms	5,108	\$67	14,439	\$208
Unwrought and waste and scrap (selenium content) do.	377,785	8,286	333,289	7,815
Silicon:				
Ferrosilicon metric tons	238,983	134,993	183,214	93,455
Metal do.	66,383	114,385	43,386	100,373
Silver:				
Bullion (refined) kilograms	2,697,926	437,380	2,525,133	338,514
Doré and precipitates do.	48,449	8,741	151,836	25,740
Ore and concentrates do.	90,202	23,203	21,422	3,659
Waste and scrap do.	507,649	86,421	1,452,501	153,299
Tantalum:				
Ores and concentrates (includes synthetic) thousand kilograms	1,067	27,053	1,000	20,609
Unwrought (alloys, metal, powders, and waste and scrap) do.	96	9,761	137	11,462
Wrought do.	3	1,028	2	765
Tellurium (unwrought and waste and scrap) kilograms	34,012	3,928	29,255	3,073
Thallium (unwrought waste and scrap) do.	450	61	1,013	184
Thorium:				
Compounds do.	18,598	595	42,609	1,270
Ore and concentrate metric tons	800	686	—	—
Ore metal (excludes monazite) kilograms	188,624	33	205,100	31
Tin:				
Compounds metric tons	426	2,493	245	1,906
Concentrates (tin content) do.	—	—	1	6
Dross, skimmings, residues, scrap, tin alloys, n.s.p.f. do.	6,788	35,291	5,855	33,132
Metal (unwrought) do.	33,810	215,863	29,102	161,725
Tin foil, powder, flitters, metallics and manufactures, n.s.p.f. do.	XX	2,086	XX	1,867
Tinplate and terneplate do.	293,426	199,036	276,326	195,659
Tinplate scrap do.	8,488	1,782	10,109	2,240
Titanium:				
Concentrates:				
Ilmenite do.	345,907	22,962	213,886	24,071
Rutile, natural and synthetic do.	274,605	127,664	127,664	127,664
Titaniferous iron ore do.	2,818	2,169	27,012	1,593
Titanium slag do.	373,623	89,450	408,302	105,792
Metal:				
Ingots and billets do.	162	47	24	1,095
Powder do.	20	526	34	697
Unwrought do.	1,093	10,398	612	5,451

See footnotes at end of table.

TABLE 9—Continued
**U.S. IMPORTS FOR CONSUMPTION OF PRINCIPAL MINERALS AND PRODUCTS,
 EXCLUDING MINERAL FUELS**

Mineral	1990 ^a		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	
METALS—Continued					
Titanium—Continued:					
Metal—Continued:					
Waste and scrap	metric tons	3,037	\$17,550	2,666	\$8,503
Wrought bars, castings, foil, pipes, plates, profiles, rods, sheet, strip, tubes, wire, and other)	do.	1,266	35,746	914	24,014
Other (includes bars, blooms, sheet, slabs, and other unwrought)	do.	193	2,359	141	1,561
Pigments (dioxides and oxides)	do.	147,592	279,602	166,094	285,290
Tungsten (tungsten content):					
Ammonium tungstate	do.	462	3,463	842	6,756
Ferrotungsten	do.	493	2,739	525	3,128
Miscellaneous tungsten-bearing materials (carbide, chlorides, oxides, metal-bearing materials, tungstates, unwrought, waste and scrap, and wrought)	do.	2,620	46,307	6,246	71,114
Ore and concentrates	do.	6,420	31,301	7,837	43,269
Vanadium:					
Ferrovandium (vanadium content)	kilograms	244,250	3,720	419,573	5,367
Pentoxide (anhydride, vanadium content)	do.	82,627	719	132,904	943
Vanadium-bearing materials [ash and residues, slag, other (includes spent catalyst), pentoxide content]	do.	6,866,041	12,657	2,063,523	5,187
Zinc:					
Blocks, pigs, slabs	metric tons	631,742	991,562	549,137	619,880
Dross, ashes, and fume (zinc content)	do.	6,411	5,942	6,483	4,658
Dust, powder, flakes	do.	8,834	17,724	15,424	26,169
Ore and concentrates (zinc content)	do.	46,684	17,970	45,419	22,110
Sheets, plates, strips, and other forms	do.	929	1,641	539	877
Waste and scrap	do.	31,720	15,101	31,596	14,185
Oxide	do.	49,454	71,998	38,215	43,712
Compounds	do.	11,653	11,451	9,891	9,553
Other (anodes, manufactures, and unwrought alloys)	do.	XX	7,772	XX	22,765
Zirconium:					
Ore and concentrates	do.	26,783	12,407	35,706	13,772
Unwrought waste and scrap	do.	128	880	197	1,347
Totals ²		XX	31,657,000	XX	32,068,000
INDUSTRIAL MINERALS					
Abrasive materials (natural and artificial)		XX	512,766	XX	480,880
Asbestos fibers	metric tons	41,348	10,772	34,765	8,900
Barite:					
Barium chemicals	do.	28,429	22,165	29,382	22,551
Crude and ground	do.	1,044	46,300	887,205	41,304
Witherite	do.	34	23	18	8
Boron (contained boric oxide):					
Boric acid	thousand metric tons	6	3,921	5	3,784

See footnotes at end of table.

TABLE 9—Continued
**U.S. IMPORTS FOR CONSUMPTION OF PRINCIPAL MINERALS AND PRODUCTS,
 EXCLUDING MINERAL FUELS**

Mineral	1990 ^a		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	
INDUSTRIAL MINERALS—Continued					
Boron (contained boric oxide)—Continued:					
Colemanite	thousand metric tons	12	\$3,310	18	\$4,389
Ulexite	do.	29	7,360	16	4,060
Bromine:					
Compounds	thousand kilograms	20,359	64,512	15,880	71,322
Elemental	do.	756	508	146	199
Calcium:					
Metal	kilograms	651,000	3,779	821,457	5,238
Chloride (crude)	metric tons	145,534	21,541	124,094	18,610
Other compounds	do.	57,286	44,871	84,119	45,031
Cement: Hydraulic and clinker	thousand short tons	13,273	533,047	8,701	402,578
Clays and clay products	thousand metric tons	30	11,988	35	13,249
Diatomite	metric tons	625	294	436	162
Feldspar	do.	11,318	723	17,876	1,124
Fluorspar:					
Aluminum fluoride	do.	35,604	40,295	33,326	33,424
Cryolite	do.	7,306	6,775	3,359	3,448
Fluorspar	do.	513,921	65,938	371,407	49,435
Hydrofluoric acid	do.	101,792	109,384	82,370	89,067
Gemstones:					
Coral and similar materials (unworked)	thousand carats	2,792	7,504	2,556	6,746
Diamond	do.	7,528	3,955,222	8,482	3,992,023
Emeralds (cut but unset)	do.	3,720	162,375	3,939	165,508
Pearls (natural, cultured, and imitation)		NA	26,645	NA	23,737
Rubies and sapphires (cut but unset)	thousand carats	5,817	180,375	5,880	152,475
Other precious or semiprecious stones		NA	271,266	NA	294,168
Graphite:					
Natural (amorphous, crystalline flake, lump or chip, and natural n.e.c.)	metric tons	50,213	35,222	33,544	21,662
Electrodes (electric furnace)	do.	38,317	63,499	26,871	45,635
Gypsum:					
Crude	thousand short tons	8,726	61,009	7,633	52,070
Plasters	do.	1	236	11	258
Boards	do.	272	22,786	88	7,842
Other	do.	XX	26,174	XX	27,971
Iodine:					
Crude	thousand kilograms	3,139	43,256	3,503	35,594
Potassium iodide	do.	29	297	52	502
Iron oxide pigments:					
Natural	metric tons	1,956	1,359	3,288	1,624
Synthetic	do.	32,141	35,918	31,437	37,736
Kyanite (andalucite)	do.	17,700	2,942	5,140	933
Lime:					
Hydrated	short tons	29,920	2,147	26,588	1,977
Other lime	do.	143,277	8,245	147,339	9,091

See footnotes at end of table.

TABLE 9—Continued
**U.S. IMPORTS FOR CONSUMPTION OF PRINCIPAL MINERALS AND PRODUCTS,
 EXCLUDING MINERAL FUELS**

Mineral	1990 ^a		1991		
	Quantity	Value (thousands)	Quantity	Value (thousands)	
INDUSTRIAL MINERALS—Continued					
Lithium:					
Carbonate	kilograms	4,196,834	\$8,381	3,109,83	\$7,414
Hydroxide	do.	471	20	20,375	128
Magnesium compounds:					
Calcined dolomite	metric tons	38,441	3,639	27,852	3,370
Caustic-calcined magnesia	do.	83,885	13,957	107,848	15,891
Compounds (chlorides, hydroxide and peroxide, and sulfates)	do.	33,046	9,238	34,384	9,921
Dead-burned and fused magnesia	do.	155,010	32,858	146,530	30,209
Magnesite (crude)	do.	1,957	722	1,956	712
Other magnesia	do.	5,037	8,573	4,109	7,712
Mica:					
Scrap and flake:					
Powder	do.	9,142	5,133	9,725	5,219
Waste	do.	4,034	987	3,630	996
Sheet:					
Unworked	do.	1,615	2,051	1,422	1,608
Worked	do.	1,085	7,431	918	6,835
Nepheline syenite (crushed and ground)	do.	276,000	12,200	289,000	13,069
Nitrogen compounds:					
Anhydrous ammonia	thousand short tons	1,821	178,951	2,184	232,894
Fertilizer materials	do.	7,719	847,304	7,159	822,102
Industrial chemicals	do.	71	65,852	64	59,444
Peat moss (poultry and fertilizer grade)	short tons	598,802	87,533	631,845	96,132
Perlite (crude)	do.	*65,000	*1,775	*60,000	*1,597
Phosphate rock and phosphate materials	thousand metric tons	477	46,365	574	50,620
Potash:					
Potassium chloride	metric tons	6,816,000	520,000	7,348,700	528,500
Potassium nitrate	do.	36,100	10,100	22,300	6,000
Potassium sulfate	do.	51,900	9,500	57,000	10,100
Potassium sodium nitrate mixtures	do.	47,800	5,500	39,000	5,000
Pumice:					
Crude or unmanufactured	do.	266,604	7,858	86,423	10,047
Wholly or partially manufactured	do.	13,704	2,021	2,850	1,382
Quartz crystal (lacas)	thousand kilograms	NA	NA	NA	NA
Salt	thousand short tons	6,580	88,419	6,821	87,380
Sand and gravel:					
Construction	do.	1,742	22,912	1,465	16,638
Industrial	do.	73	3,148	91	932
Sodium compounds:					
Soda ash	metric tons	145,534	20,495	134,312	21,299
Sodium sulfate	do.	161,665	13,155	156,900	13,807
Stone:					
Crushed (chips and fines)	thousand short tons	4,972	35,310	5,728	38,649
Dimension	do.	NA	567,019	NA	462,778

See footnotes at end of table.

TABLE 9—Continued
**U.S. IMPORTS FOR CONSUMPTION OF PRINCIPAL MINERALS AND PRODUCTS,
 EXCLUDING MINERAL FUELS**

Mineral	1990 ^r		1991	
	Quantity	Value (thousands)	Quantity	Value (thousands)
INDUSTRIAL MINERALS—Continued				
Strontium:				
Celestite (strontium sulfate) metric tons	48,724	\$4,189	33,204	\$2,577
Compounds (carbonate and nitrate) kilograms	20,162,343	12,982	16,629,319	10,803
Sulfur:				
Elemental thousand metric tons	2,571	206,450	3,020	241,749
Sulfuric acid (100% H ₂ SO ₄) metric tons	1,689,618	62,581	1,845,255	57,727
Talc (unmanufactured) do.	65,099	11,056	66,791	11,925
Vermiculite thousand short tons	50	NA	42	NA
Total industrial minerals ²	XX	9,352,000	XX	9,069,000
Total ²	XX	41,009,000	XX	41,137,000

^rEstimated. ^rRevised. NA Not available. XX Not applicable.

¹Less than 1/2 unit.

²Data may not add to totals shown because of rounding.

TABLE 10
COMPARISON OF WORLD AND U.S. PRODUCTION OF SELECTED NONFUEL MINERAL COMMODITIES

Mineral		1990			1991		
		World production ¹	U.S. production	U.S. percent of world production	World production ¹	U.S. production	U.S. percent of world production
METALS, MINE BASIS							
Antimony ²	metric tons	'66,846	W	NA	64,730	W	NA
Arsenic trioxide ³	do.	'53,976	—	—	47,084	—	—
Bauxite ⁴	thousand metric tons	'109,601	W	NA	109,172	W	NA
Beryllium concentrates (gross weight)	metric tons	'7,119	'4,548	64	6,607	'4,339	66
Bismuth	do.	'3,359	W	NA	3,301	W	NA
Chromite (gross weight)	thousand metric tons	'12,848	—	—	13,237	—	—
Cobalt ²	metric tons	'35,709	—	—	26,583	—	—
Columbium-tantalum concentrate (gross weight)	do.	'32,103	—	—	33,593	—	—
Copper ²	thousand metric tons	'8,693	'1,588	18	8,820	1,631	18
Gold ²	kilograms	'2,127,398	'294,527	14	2,111,522	289,885	14
Iron ore (gross weight)	thousand metric tons	'928,427	56,408	6	897,929	55,516	6
Lead ²	do.	'3,390	'496	15	3,318	477	14
Manganese ore (gross weight)	thousand short tons	'28,036	—	—	24,666	—	—
Mercury	metric tons	'5,061	W	NA	4,536	W	NA
Molybdenum ²	do.	'122,232	61,611	'50	112,224	53,364	48
Nickel ²	thousand metric tons	'937	(⁵)	(⁶)	923	(⁶)	1
Platinum-group metals ³	kilograms	'288,502	'7,740	3	291,678	'7,780	3
Silver ²	metric tons	'15,122	'2,125	14	14,723	1,848	13
Tin ²	do.	'218,518	W	NA	196,695	W	NA
Titanium concentrates (gross weight):							
Ilmenite	thousand metric tons	'3,952	W	NA	3,486	W	NA
Rutile	do.	'475	W	NA	450	W	NA
Tungsten ²	metric tons	'51,918	W	NA	42,960	W	NA
Vanadium ²	do.	'30,606	W	NA	26,435	W	NA
Zinc ²	thousand metric tons	'7,320	543	7	7,282	547	8
METALS, SMELTER BASIS							
Aluminum (primary)	do.	'17,977	4,048	23	18,194	4,121	23
Cadmium	metric tons	'20,493	1,678	8	20,673	1,676	8
Cobalt	do.	'25,316	—	—	23,922	—	—
Copper (primary and secondary) ⁷	thousand metric tons	'9,087	1,463	16	9,052	1,487	16
Iron, pig	do.	'550,973	'50,028	9	528,485	44,533	8
Lead, refined (primary and secondary) ⁸	do.	'5,830	'1,326	'23	5,642	1,229	22
Magnesium (primary)	metric tons	'353,512	139,333	'39	339,269	131,288	39
Nickel ⁹	do.	'883,015	3,701	(⁶)	875,636	7,065	1
Selenium ¹⁰	kilograms	'1,793,633	286,755	16	1,808,551	259,522	14
Steel, raw	thousand metric tons	'770,638	89,726	12	733,673	79,738	11
Tellurium ¹⁰	kilograms	'70,543	W	NA	78,797	W	NA
Tin ¹¹ (primary and secondary)	metric tons	'240,887	W	NA	220,364	W	NA
Zinc (primary and secondary)	thousand metric tons	'7,053	358	5	7,082	377	5
INDUSTRIAL MINERALS							
Asbestos	do.	'3,819	W	NA	3,490	W	NA
Barite	do.	'5,595	¹² 439	8	5,271	¹² 448	8
Boron minerals	do.	'2,966	¹² 1,094	'37	2,988	¹² 1,240	41
Bromine	metric tons	'416,900	¹² 177,000	'42	401,200	¹² 170,000	42
Cement, hydraulic	thousand short tons	'1,270,970	78,606	6	1,312,302	'77,000	6

See footnotes at end of table.

TABLE 10—Continued
COMPARISON OF WORLD AND U.S. PRODUCTION OF SELECTED NONFUEL MINERAL COMMODITIES

Mineral		1990			1991		
		World production ¹	U.S. production	U.S. percent of world production	World production ¹	U.S. production	U.S. percent of world production
INDUSTRIAL MINERALS—Continued							
Clays:							
Bentonite ³	thousand metric tons	¹ 9,733	¹² 3,474	³ 6	9,264	^o ¹² 3,432	37
Fuller's earth ¹⁰	do.	³ 3,480	¹² 2,307	66	4,012	^o ¹² 2,740	68
Kaolin ³	do.	² 23,673	¹² 9,762	⁴ 1	24,748	^o ¹² 9,575	39
Diamond, natural	thousand carats	¹ 101,566	—	—	104,386	—	—
Diatomite	thousand metric tons	¹ 1,629	^r ¹² 631	³ 9	1,556	610	39
Feldspar	do.	⁵ 2,269	630	¹ 2	5,167	580	11
Fluorspar	do.	⁵ 5,025	^o ⁵ 64	1	4,354	^o ⁵ 58	1
Graphite, natural	metric tons	⁶ 44,379	—	—	628,894	—	—
Gypsum	thousand short tons	¹ 104,584	16,406	¹ 16	103,544	15,456	15
Iodine, crude	metric tons	¹ 6,114	1,973	12	16,159	1,999	12
Lime ¹³	thousand short tons	¹ 148,268	¹² 17,481	12	146,426	¹² 17,303	12
Magnesite, crude	thousand metric tons	¹ 11,117	W	NA	10,944	W	NA
Mica (including scrap and ground)	metric tons	² 10,786	108,845	⁵ 2	198,347	102,830	52
Nitrogen: N content of ammonia	thousand short tons	¹ 107,561	¹ 13,806	13	103,308	13,991	14
Peat ¹⁴	do.	¹ 196,612	763	(^o)	185,389	697	(^o)
Perlite	do.	² 2,017	¹² 639	³ 2	1,998	¹² 567	28
Phosphate rock (gross weight)	thousand metric tons	¹ 154,356	46,343	30	146,859	48,096	33
Potash (K ₂ O equivalent)	do.	² 27,685	1,713	6	25,548	1,749	7
Pumice ¹⁰	do.	¹ 10,739	¹² 443	4	10,802	¹² 401	4
Salt ¹³	thousand short tons	² 200,989	¹² 40,738	20	202,450	¹² 39,620	20
Sand, industrial (silica)	do.	¹ 129,468	¹² 28,406	² 2	121,715	¹² 25,600	21
Sodium compounds, n.e.s. (natural and manufactured):							
Soda ash	thousand metric tons	³ 2,273	9,156	28	31,344	9,005	29
Sulfate	do.	⁴ 8,70	¹² 665	¹ 4	4,837	¹² 696	14
Strontium ¹⁰	metric tons	² 23,527	—	—	240,356	—	—
Sulfur, all forms	thousand metric tons	⁵ 8,154	11,560	20	55,592	10,816	19
Talc and pyrophyllite ¹⁵	do.	⁹ 9,084	1,267	¹ 4	8,932	1,037	12
Vermiculite ¹⁰	short tons	⁶ 38,462	^o ¹² 230,000	36	576,108	¹² 185,000	32

¹Estimated. ²Revised. NA Not available. W Withheld to avoid disclosing company proprietary data.

³Those commodities for which U.S. data are withheld to avoid disclosing company proprietary data, the world total excludes U.S. output and the U.S. percent of world production cannot be reported.

⁴Content of ore and concentrate.

⁵World total does not include an estimate for China.

⁶U.S. figures represent dried bauxite equivalent of crude ore; to the extent possible, individual country figures that are included in the world total are also on the dried bauxite equivalent basis, but for some countries available data are insufficient to permit this adjustment.

⁷Shipments.

⁸Less than 1/2 unit.

⁹Primary and secondary blister and anode copper, including electrolytic refined copper that is not included as blister or anode.

¹⁰Includes bullion.

¹¹Refined nickel plus nickel content of ferronickel, nickel oxide, and other nickel salts.

¹²World total does not include estimates for output in the U.S.S.R. or China.

¹³Includes tin content of alloys made directly from ore.

¹⁴Quantity sold or used by producers.

¹⁵Data for the United States include Puerto Rico.

¹⁶Data for the United States exclude proprietary amounts of fuel peat.

¹⁷The figure for the United States for 1991 excludes proprietary pyrophyllite production.

**FIGURE 1
A TYPICAL SURVEY FORM**

Form 6-1066-M
Fer. (6-91)



A03

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
WASHINGTON, D.C. 20241
IRON ORE (Usable ore)

O.M.B.No. 1032-0006.
Approval Expires: 12/31/93
**INDIVIDUAL COMPANY
DATA-PROPRIETARY**

Unless authorization is granted in the section above the signature, the data furnished in this report will be treated in confidence by the Department of the Interior, except that they may be disclosed to Federal defense agencies, or to the Congress upon official request for appropriate purposes.

FACSIMILE NUMBER
1-800-543-0661

(Please correct if name or address has changed.)

Public reporting burden for this collection of information is estimated to average 30 MINUTES per response, including the time for reviewing instructions, searching data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Bureau of Mines, Branch of Statistics and Methods Development, Washington D.C. 20241, and Office of Information and Regulatory Affairs, Office of Management and Budget, Washington D.C. 20503.

Please complete and return this form in the enclosed envelope by the 15th of the month following the report period. Additional forms are available upon request.

In completing this form, reasonable estimates may be used wherever exact figures are not available. Use zero (0) when appropriate. DO NOT REPORT DECIMALS OR FRACTIONS.

"Collection of non-fuel minerals information is authorized by Public Law 96-479 and the Defense Production Act. This information is used to support executive policy decisions pertaining to emergency preparedness and defense and analyses for minerals legislation and industrial trends. The Bureau relies on your voluntary and timely response to assure that its information is complete and accurate."

SECTION 1. Mine or group covered by this report.

Name _____ State _____ County _____

SECTION 2. Stocks, production, and shipments of usable ore for the report month.

Report only ore products as shipped to consumer, such as direct-shipping ore, concentrates, or agglomerates. Report ores produced in the United States only; do not include imports.

Usable ore (1)	Code	Weight unit Mark (X) one (2)		Physical inventory Adjustment only (3)	Beginning stocks (4)	Production (5)	Shipments (6)	Ending stocks (7)
		Long tons (4)	Metric tons (6)					
Iron ore (Containing less than 5% Mn, natural)...	201							

SECTION 3. Please indicate any mines opened or closed by your company during the month. _____

Remarks:

Name of person to be contacted regarding this report				Tel. area code	No.	Ext.
Address	No.	Street	City	State	Zip	
May tabulations be published which could indirectly reveal the data reported above?				<input type="checkbox"/> (1) Yes	<input type="checkbox"/> (2) No	
Signature			Title	Date		

MINING AND QUARRYING TRENDS IN THE METALS AND INDUSTRIAL MINERALS INDUSTRIES

By Brian T. Brady, Gregory J. Chekan, and Charles V. Jude

Dr. Brady is a physicist who has been with the U.S. Bureau of Mines, Denver Research Center, for over 25 years. Mr. Chekan is a geologist who has been with the U.S. Bureau of Mines, Pittsburgh Research Center, for 4 years. Mr. Jude is a mining engineer at the Denver Research Center who has extensive industrial and research experience in block caving mining operations. Domestic survey data were prepared by Stephen D. Smith, mineral data assistant.

MINING HIGHLIGHTS

Summary

The year 1991 recorded unprecedented change throughout the world; war in the Middle East, economic recession in key industrial nations, upheaval in Eastern Europe, and the disintegration of the former U.S.S.R. These issues and growing environmental concerns will affect the entire world mining industry.

Environmental issues continue to have an ever greater effect on industrial minerals. In the United States, major issues involving the Clean Air Act, Clean Water Act, and the recent Stormwater Rule by the U.S. Environmental Protection Agency (EPA) affect many types of mineral operations. Significant developments include an important decision in 1991 by a Federal Appellate Court to overturn EPA's asbestos ban on certain products, partly on environmental grounds, and proposed legislation that would overhaul or abandon the 1872 Mining Act. On a global scale, prominent issues include environmental concerns over mining in the Antarctic and Arctic regions and a cutback in plans to clean up the Kola Peninsula in the Commonwealth of Independent States (C.I.S.).

In the United States, the EPA Stormwater Rule will have a pronounced effect on industrial mineral operations. EPA claims that stormwater runoff is the leading source of water pollution in the country. Under the new rule, mine operators will be required to outline pollution prevention measures (spill prevention and containment) before a mining permit is granted. The rule is expected to apply to a wide variety of more than 12,000 operations, including crushed rock operations. In some cases, group-permit applications will be allowed.

In October 1991, a Federal Appellate Court in New Orleans overturned a 1989 EPA ruling prohibiting the use of asbestos in many products such as brake linings and construction-related products such as coatings, shingles, and cement-bounded pipe. The EPA ruling was intended to gradually phase out the use of products containing asbestos by 1997. Although the court did not dispute the possible health hazards, it said EPA "presented insufficient evidence to justify the asbestos ban." Although the court decision was welcome news to the remaining producers of asbestos and its products in the United States and Canada, the proposed ban is likely to resurface in the court system in the near future.

Considerable press has been given to proposed legislation aimed at overhauling or discarding the Mining Law of 1872.

Antimining and environmental forces support such changes, but opponents fear these changes would cripple the mining industry. A chief point of contention is the proposed 8% gross Federal royalty on production. Many observers have noted that this royalty level could force many mines to close because it would exceed their profits. Other significant points of disagreement include expensive reclamation regulations that would require a performance bond for reclamation before mining, conditions on the right to mine, and patents.

Another first last year was the announcement by the Robertson Group public limited company that it had acquired sales rights from the Soviet Ministry of Geology for limited quantities of previously unavailable maps showing locations of Soviet diamonds, gas, gold, industrial minerals, metallic minerals, and oil.¹

FMC Corp. announced plans to develop brine deposits in northern Argentina that could make FMC a major producer of lithium carbonate, which is used in producing batteries, ceramics, glass, and rubber. The projected output of 7,000 to 15,000 metric tons per year compares with current annual world production of about 30,000 tons.²

The discovery of a new, very white marble deposit has been made north of Atlanta, GA. Reserves are estimated at

40 million tons. The marble is sufficiently pure to be used in paper.

The graphite industry continues to expand in Canada. Although some deposits are not high grade, the fact that many contain the flake type of graphite makes them easy to produce. Despite low grade and high labor costs, the low beneficiation costs and high demand for flake graphite results in a good profit and is expected to continue.

In Brazil, despite declining domestic consumption and export value of aluminum, State-controlled Companhia Vale do Rio Doce announced plans to significantly increase production of bauxite and aluminum over several years, with projected aluminum sales of about \$750 million annually and doubling by 1995.

The dimension stone industry has been growing steadily during the past decade. Among market economy countries, Italy, Spain, and the United States are the leading producers, with Italy producing more than 20% of the total. Most people are aware of world-famous Italian marbles, but few realize that granites are a major component of Italy's dimension stone production. Spain has a rapidly growing granite industry, particularly the "Spanish Pink" granite that makes up one-half of that country's total granite production.

China has become a major dimension stone producer, particularly in granite. Estimates show that granite block production is about one-third greater than that for Italy and three times greater than U.S. production. China also has a marble stone industry, although it is much smaller.

Many important developments occurred in the diamond industry in 1991, and China again made news with the discovery of a 60.5-carat stone in Liaoning Province (northeast China). Eastern China contains many kimberlites, and some are known to contain diamonds. A smaller number of diamond placer deposits are also known. Although data are sketchy, China could become a major diamond producer.

Another important diamond discovery occurred when results from core samples

of kimberlites in Saskatchewan indicated that Canadian Province may eventually have its first diamond mine. Many diamonds have been found in the samples (up to 0.6 carat) and some are gem quality.

Early in 1991, Poseidon's Bow River diamond operation in Western Australia announced it had exceeded its 1990 goal by almost 40% and had produced more than 720,000 carats. About 20% of the stones in this world-class deposit are gem quality, including pink stones. The company also announced that the alluvial gravels containing these diamonds occupy a larger area than originally realized.

De Beers and Botswanan interests renewed their 5-year agreement by which all diamonds mined by the De Beers-Botswanan Company, Debswana, will be marketed through the Central Selling Organization. Despite record production, the lower quality mix of stones in 1990 means a sharply lower gross national product for Botswana in 1991. Diamonds are a major component of the Botswanan economy.

In other diamond developments, De Beers-owned Tanex Ltd. signed an agreement with the Government of Tanzania to prospect for diamonds over a sizable area in the northern part of that country. Previous diamondiferous kimberlites in Tanzania have proven uneconomical.

De Beers has not fared as well in Zimbabwe with regard to its River Branch diamond claims. The Government insists that its Minerals Marketing Corp. act as agents and take a percentage of the production for domestic use. De Beers, although leaving the door open for future negotiations, may forfeit its claims after 2 years of disagreement. Other companies are showing an interest in exploring this area.

An Indonesian Diamond Corp. is developing an alluvial mining operation at Danau Seran that, at full production, should produce from 30,000 to 54,000 carats per year with a high proportion of gems. The company also expects to extract gold and platinum from the gravel.

Finally, Angola rejoined the Central Selling Organization. That country had been the only major diamond producer outside the organization since 1985.

The fertilizer industry in 1991 had a very slow year. Although production declined in some countries and planned expansions in the former U.S.S.R. were placed on hold, there are plenty of potash reserves. Demand for this commodity is not expected to surge in the near term. One expansion that concerns the Association of South-East Asian Nations countries is an agreement to set up a company to mine potash in Thailand with an expected production of 1 million tons per year by 1995.

Mining of phosphate rock has ended at Rhône-Poulenc's Mine at Mount Pleasant, TN. The company said the high cost for electricity to operate the thermal phosphoric acid process is uncompetitive compared to wet processing. The plant will continue to process its inventory of mined phosphate rock and expects to close in 1993.

Some sulfur prices have risen, in part because of the removal of some production by the Persian Gulf War. This loss portends tight supplies and higher prices until more projects come on-line and Middle Eastern production returns to normal.

The mineral sands industry is changing, particularly with respect to rutile and ilmenite, which serve as sources for titania. When heavy metals were banned, especially lead, titania became extremely important. Its high index of refraction (high reflectivity), relative stability, and nontoxic nature made it an ideal component for many applications such as ceramic glazes, enamels, paints, pigments, and plastics. Demand for titania and zirconia, with its special refractory applications, is the major reason for growth in mineral sands operations.

Despite a recession-related drop in sales in 1990, plants using the newer chloride process on mineral sands, developed by Du Pont De Numours, are expanding capacity. This process uses 50% less energy and generates 80% less waste than the older sulfate process,

which is still used widely in Europe. By the end of 1991, capacity at chloride plants will have increased by 233,000 metric tons per year.

Hazcare Pty. Ltd., a subsidiary of Pioneer Resources, has signed a preliminary agreement with Sierra Leone to mine and process deposits containing rutile, ilmenite, and lesser amounts of zircon. Richard Bay Minerals' plans to mine beach sands off the South African coast for rutile and ilmenite have run into problems with environmentalists because this coastal area is considered by some to be an internationally important wetlands area.

Uranium inventories remained high last year, similar to those of 1990, and prices stayed low. Industry analysts expect little increase in demand in the near term. Market conditions have reduced output at many mines and closed several mines. Marginal producers cannot compete in such an environment.

Yugoslavia closed its only uranium mine in 1990, and its last shipment of uranium cake was sent to the United States for processing in 1991. Czechoslovakia is expected to close several mines over the next few years, partly due to exhaustion of reserves.

Now that contracts to supply the U.S.S.R. have expired, plants in Czechoslovakia and eastern Germany must find new markets for their production. Once Canada's uranium-rich Cigar Lake project—said to be on schedule—begins production, it should be able to supply most needs in the Western Hemisphere.

Environmentalists are in a dilemma. Most have long opposed nuclear power, but they also face a growing awareness that fossil-fuel power generation has produced global environmental problems. Ironically, nuclear power may eventually regain stature with its opponents if acceptable safety features and waste disposal methods can be built into nuclear plants.

Izhorskiy Works in St. Petersburg (Leningrad), C.I.S., is apparently planning to market a new generation of small nuclear power stations that are small enough to be transported by motor

vehicle, motor boat, or helicopter. The units are claimed to be totally automatic and accident-proof, with a 25-year lifetime. These units will be marketed as ideal sources of electricity for villages, particularly in remote or coastal areas.³

Production Overview

Total processed nonfuel mineral materials in the United States during 1991 were valued at approximately \$297 billion. Raw nonfuel minerals production in 1991 was estimated at \$30.8 billion, a 5.8% decline from that in 1990. The metals component of production value has fluctuated much more than the industrial minerals component, reflecting the greater volatility of metal prices.

Employment in metal mining rose slightly in 1991, but this gain was more than offset by a decline in employment in industrial mineral mining, resulting in an overall decline of 3.0% to 164,000 workers in 1991. Prices of several major metals declined during 1991, reflecting weakness in the economy and causing some metal mines to shut down or reduce operation.

Industrial Minerals

The slowdown of the U.S. economy influenced the construction industry by affecting the demand for construction aggregates. The demand in 1991 for crushed stone was estimated to be about 1.1 billion short tons (st), and the demand for construction sand and gravel was expected to be about 820 million st. This is about a 10% decrease in demand for both commodities. The U.S. demand for cement declined 12% to 78.7 million st. This was the fourth consecutive year of decline following the peak reached in 1987. In addition, passage of the highway bill in 1991 should spur production in the portland cement industry in early spring when weather warms and construction crews start repairing the highway system.

Agricultural Minerals

Nitrogen represents the largest fertilizer market, with annual demand of about 80 million nutrient tons compared with 38 million tons for phosphates and about 28 million tons for potash. Rising nitrogen imports into the United States have displaced about 15% of U.S. capacity over the past decade. But over the past 18 months, the nitrogen business has been good to those who persevered. Phosphate rock production in 1991 was approximately the same as that of 1990. The world's potash producers stayed in overcapacity, but several producers operated at partial capacity to maintain prices.

While the breakup of the C.I.S. aided some of the agricultural minerals industry, sulfur demand there dropped sharply. This disrupted international trading patterns for sulfur and caused an all-out trade war during 1991. The result was a 40% drop in sulfur prices in just 12 months to the lowest mark since 1979. A complete recovery depends on the ability to predict what course the new C.I.S. will take. Eastern Europe and the former U.S.S.R. will continue to create interesting challenges for all types of minerals industries.

Metals

Throughout 1991, the United States remained totally dependent on foreign sources of bauxite for the production of primary aluminum metal. Despite a decline in primary aluminum ingot prices, domestic production continued to increase. World demand for aluminum metal leveled off in 1991, while primary aluminum ingot reserves rose dramatically during the year. This increase in reserves and the decline in aluminum ingot prices caused many companies throughout the world to begin to reevaluate the status of their higher cost aluminum reduction facilities.

Copper.—For the first time since 1975, the United States will be a net exporter of copper for 1991. Disruptions to the world copper mine production continued,

including strikes, mine accidents, and at yearend, civil unrest in Zaire. Even so, the supply of copper concentrates from mines in the United States and Chile was expected to surpass available smelter capacity for some time. Environmental concerns continued to delay any new mine or smelter copper project in the United States and Canada. U.S. exports of concentrates, refined copper, and semifabricates continued to be high; U.S. net imports of brass mill semifabricates decreased for the seventh consecutive year.

Gold.—Although price prospects were poorer than in past years, the domestic gold mining industry completed its 12th successive year of growth, and for the 2d consecutive year, the United States was the 2d largest gold producer in the world, after the Republic of South Africa. However, of the 112 operations that produced gold in 1990 or started production in 1991, 32 are no longer being mined. Eighteen of these are continuing to produce limited amounts of gold from residual leaching operations. The other 14 have been shut down and are no longer producing gold. Domestic exploration leveled off, and many companies redirected their search for gold elsewhere, often to Latin America. Environmental pollution abatement continued to be of concern to domestic producers. The demand for gold in jewelry, dentistry, and industrial sectors remains strong despite the general weakness in the domestic economy.

Iron and Steel.—The iron and steel industry suffered from weak markets, partly the result of uncertainty created by the Persian Gulf War, which began in August 1990. Nevertheless, a large amount of steel was produced in the last quarter of 1990 in expectation of an imminent upturn in the economy. This resulted in an overhang of stocks at the beginning of 1991 and a drastic fall in production. Capacity utilization dropped to about 65% in February and stayed below 75% for the remainder of the year. As a result, steel production dropped by

12% compared with that of 1990, while shipments of steel dropped by only 7% because of the industry's reserves. Shipments to the main markets (i.e., service centers, automobile producers, and construction) were 12% to 18% off their previous level.

Lead.—The United States continued to be a significant net exporter of lead concentrates for the second straight year as the two new Alaskan mines neared capacity production. This occurred in spite of the shutdown of two Missouri lead mines and several Western precious-metal and zinc-lead producers owing to lower prices. Domestic consumption of lead declined significantly in 1991 by about 75,000 metric tons. Secondary production remained strong, a result of strict battery disposal and/or mandatory recycling laws in 37 States. At yearend, legislative action was pending in six other States.

Platinum and Palladium.—U.S. production of platinum and palladium in 1991 was held at the same level as that in 1990. Lower prices for platinum made it necessary for the Nation's only mine and smelter, Stillwater Complex, near Nye, MT, to reduce the work force by 113. The price of platinum declined sharply as a result of a series of announcements that some companies had developed less expensive substitutes for platinum-group metals (PGM) used in auto catalysts. Two Japanese automobile companies announced new palladium-only auto catalysts; a South African firm announced a manganese-base auto catalyst; and a researcher in the Netherlands claimed development of an auto catalyst based on copper and chromium.

Silver.—U.S. silver production declined for the first time in 6 years. Domestic production was adversely affected by the closure or curtailment of operation at a number of mines, especially in the Coeur d'Alene area in Idaho. Mining activity was reduced in response to continued buildup of silver reserves and to the declining price of

silver, which fell to its lowest level in nearly two decades. Over the past few years, U.S. silver production has continued to increase despite declining prices and less from active silver mines. This increase is in response to increased byproduct silver production from gold leaching operations. In 1991, however, the recovery of byproduct silver was apparently unable to compensate for the lower production from primary silver mines.

Tantalum.—There has been no significant tantalum-mining industry since 1959, with the exception of small, unreported quantities of tantalum-bearing concentrates produced in 1989-91. Most of the world's resources of tantalum occur outside the United States, largely in Australia, Canada, Egypt, Malaysia, Nigeria, Thailand, and Zaire. In September 1991, the Defense Logistics Agency (DLA) accepted a sale offer from one of eight bidding firms to purchase 200,000 pounds (lb) of the product tantalum pentoxide for inventory in the Nation Defense Stockpile (NDS). Major uses of tantalum, as a metal powder, are in the production of electronic components, mainly in aircraft, capacitors used in computers, communication systems, missiles, ships, and weapon systems.

Zinc.—U.S. zinc mine production was at its highest level since 1965 even though six zinc-producing mines in the Western States closed during the year. Despite higher mine production, the United States continued to import most of its refined zinc because of a severe lack of smelting capacity. About one-half of the zinc concentrates produced was exported.

The General Accounting Office (GAO), the investigative arm of Congress, has determined that the gold mining industry and the Government have taken major steps to mitigate the potential threat that the use of cyanide may pose to wildlife and surface and ground waters. The report found that most cyanide-related wildlife deaths are preventable and

that most facilities have adopted improved techniques to prevent such deaths. The report GAO-RCED-91-145 is available from the GAO Document Service in Gaithersburg, MD.

Armco Steel has applied for a patent for a process it has developed over the past several years to dezinc bundles of galvanized sheet steel scrap. The process is almost the reverse of electrogalvanizing. Bales of galvanized sheet are immersed in a hot, caustic solution that has an electric current passing through it. The zinc coating is separated from the steel, which allows the steel to be recycled. With a number of automobiles containing zinc-coated steels now going to the scrap heap, steelmakers will have a way to recycle the metal from the cars. The process is 2 years away from commercial application.⁴

Lead scrap was the hottest item in the scrap exporter's arsenal in 1991, with export volumes rising by more than one-fifth over what was already a record-setting performance in 1990. U.S. traders sent abroad a total of 94,471 tons of lead scrap in 1991, up from 78,876 tons the year before. Scrap trade sources have said the growing importance of poorer countries as buyers in the international battery scrap market is a reflection of the difficulty some U.S. operators have had in ensuring that they can comply with increasingly strict environmental regulations.⁵

First National Minerals Education Conference

U.S. Bureau of Mines personnel participated in the first National Minerals Conference, held in Reno, NV, in February 1992. The event, sponsored by the Nevada Mining Association and the Nevada Department of Minerals, sought to bring together various organizations throughout the country interested in furthering student awareness of the importance of minerals and how they are recovered. Attendees included Mining Association education committees, professional societies, Government agencies, teachers and teacher organizations, educational productmakers,

and members of the mining industry. The 2-day conference included topics on the importance of minerals education, how minerals presentations can be extended to more classrooms, and panel discussions of various programs of the organizations.

Incentive Bonus Systems

Mining companies continue to use incentive bonus plans as part of their wage systems in 1991. As an example, Magma Copper Co. and its union workers agreed to an unusual 15-year contract in July. The agreement is very unique because it contains a binding arbitration provision that prevents the possibility of a strike for almost 8 years. The long-term labor contract was ratified 8 months before the current agreement expires. The new agreement provides an initial hourly increase of 35 cents and several automatic and conditional raises thereafter.

The innovative agreement is considered a key to prolonging operations in a copper mine operations at San Manuel, AZ, where underground mining of the San Manuel ore body has been scheduled to cease in 1997. The agreement allows for continued development and mining of the deeper, offset Kalamazoo ore body and results in preserving approximately 1,500 jobs.

Mexico Adopts New Mining Regulations

Mexico has adopted new national mining regulations to promote the growth of the Mexican mining industry by encouraging exploration and production and by promoting domestic and foreign investment. Among the significant changes introduced by the regulations are the mechanisms to increase foreign participation. The mechanism establishes trusts in both exploration and development of concessionable minerals. The exploration trust allows for 100% foreign ownership during a period of 30 years, with a renewal option. Through a similar trust, foreign control of mines is permitted for 12 years. After 12 years,

the foreign entity must sell at least 51% interest to Mexican citizens.

Another important step was taken to reduce government monopoly control of certain minerals. Under the new regulations, sulfur, phosphate rock, and potassium may be produced by private concerns through limited partnership with the government.

Other steps taken to promote growth and to increase participation in the mining industry include streamlining government processing of applications for approval of mineral concessions and the revision of criteria by which land is set aside within the national mineral reserves industry.

LEGISLATION AND GOVERNMENT ACTIONS

Summary

The mining industry is still waiting for definitive mine waste regulation. Resource Conservation and Recovery Act (RCRA) reauthorization has been a subject of intense debate, and novel EPA initiatives for consensus building such as Strawman and the Policy Dialogue Committee have not resolved the concerns of all interested parties. Pending RCRA reauthorization, the States have become more active in such areas as ground water protection. One particular State has proposed such stringent mining waste regulations that all future gold mining in that State could be foreclosed. The resultant uncertainty has made planning more risky, adding to new project costs. Proposed revisions to the Mining Law of 1872 have similarly been exhaustively debated without a consensus being reached. Independent studies show that there is a potential for significant reduction of exploration should the self-initiation features of the Mining Law of 1872 be repealed. The new provisions of the clean air legislation passed in 1990 seem to target the business sections rather than mining. The air toxics provisions of title III have caused considerable concern in the mining industry since many of the compounds listed as hazardous pollutants are found in mining environments.

EPA Activities—Mining Wastes

As part of its responsibilities to regulate noncoal wastes under RCRA, the EPA drafted two staff "Strawman" approaches toward the development of a minerals industry waste management regulatory program. The more recent approach, Strawman II, was released May 21, 1990. The EPA did not endorse either approach, but rather viewed them as working drafts to solicit comments from the public and other interested parties to assist in developing a mining waste management regulatory program. Unfortunately, both approaches failed to address a number of important issues that both the Departments of the Interior and Agriculture took exception to and formally addressed. Among the points EPA failed to take into account were the mandated responsibilities of the Federal land management agencies, (i.e., the Bureau of Land Management (BLM) and the U.S. Forest Service). Also, the regulatory program envisioned in Strawman II requires statutory authority beyond that currently available to the EPA in RCRA, such as the regulation of certain materials not now considered solid wastes. In general, these materials are in-process materials, such as ores being leached in heaps or dumps, or ores and subgrade ores in stockpiles.

Following the Strawman process, EPA established a Policy Dialogue Committee (PDC), which serves as a forum for continuing to refine and develop issues related to managing mining wastes. Although the PDC was to terminate by March 31, 1992, the charter has been extended and EPA will continue the committee's work beyond that date.

Reauthorization of RCRA

Activities leading to the reauthorization of RCRA are continuing to move forward. Reauthorization is necessary to avoid State-by-State changes that would create confusion at the Federal level, including the banning of shipments of interstate waste. Senator Max Baucus (D-MT), Chairman of the Senate Environment and Public Works

Environmental Protection Subcommittee, introduced a comprehensive Federal RCRA reauthorization bill, S. 976. This bill addresses the waste problem on several fronts: (1) reduces toxics in the waste stream and (2) stresses waste reduction and pollution prevention. A national goal of 50% recycling would be set for the year 2000. To ensure safe disposal, S. 976 establishes minimum Federal standards and permits for solid waste facilities.

Certain provisions of the Senate bill would affect the minerals industry. Although solid wastes generated from the extraction, beneficiation, and processing of ores and minerals are excluded from the permit guideline, standards for industrial waste management, the facility permit, and notification requirements remain. These provisions could result in significant costs for the minerals industry. Other sections of S. 976 relate to the regulation of recycled and secondary materials. These sections contain provisions that are expansive enough to subject several mine and mineral-processing activities, such as heap and dump piles, to RCRA regulation and result in additional costs. In addition, the bill includes a pollution-prevention section requiring detailed reporting on toxic generation, waste reduction, a reduction plan, goals, etc. While this provision does not specifically cover mines, it is applicable to mineral processing facilities.

In the House of Representatives, action has focused on reauthorization legislation by the Transportation and Hazardous Materials Subcommittee Chairman. The initial legislation (H.R. 3865) covered only municipal solid waste. On March 17, 1992, a substitute bill was released that includes new provisions for mining wastes. These provisions would require EPA to assist the States in program development and establishing mining waste programs.

Mineral Processing Waste

On May 20, 1991, EPA issued its final regulatory decision for the 20 special wastes from mineral processing activities.

These wastes were excluded from RCRA hazardous wastes regulations under subtitle C of the Bevill amendment. The final rule determined that subtitle C is inappropriate for all 20 wastes, because they exhibit negligible hazardous characteristics and pose low risks. The rule places 18 of the 20 wastes under the Agency's evolving subtitle D mining waste program. For the other two—phosphogypsum and phosphoric acid process wastewater—the rule concludes that neither subtitle C nor D regulation is warranted, and instead uses authorities under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) and the authority under the Toxic Substances Control Act (TSCA) to address the future generation and management of the wastes. EPA proposes to use existing RCRA and Superfund authorities to address any site-specific ground water contamination problems that are believed to pose substantial health and environmental risks. All other mineral processing wastes now are subject to regulation as hazardous wastes under subtitle C.

Revision of the Mining Law of 1872

Efforts continued in 1991 to amend the General Mining Law of 1872. Bills S. 433 and H.R. 918 were reintroduced in February 1991 and H.R. 2614 in June 1991. These bills provide for comprehensive changes to the current laws. Key arguments against the current law include (1) inadequate control of environmental damage, (2) patenting of surface ownership for \$2.50 or \$5.00 per acre, (3) lack of financial return to the government (royalties), and (4) nonmining abuses of claims. In April 1991, S. 785 was introduced to establish a commission to study existing laws and procedures relating to mining and to make recommendations for their modification.

Washington hearings on all four bills were held in June 1991. House field hearings were held in Denver, CO, Reno, NV, Santa Fe, NM, and Fairbanks, AK, during April and May 1991, and a Senate

field hearing was held during December 1991 in Salt Lake City, UT.

The Mining Law of 1872 established a policy of "self-initiation," whereby a prospector may file an unpatented mining claim if he makes a discovery. The filing of a claim establishes a property right to the minerals, subject to annual assessment and work requirements. The claimant can purchase (patent) the surface rights to a valuable mineral deposit after spending at least \$500 in development and paying the appropriate filing fees. Substantial investments may be incurred by a claimant to prove the value of a mineral deposit prior to being issued a patent.

Bills S. 433 and H.R. 918 are similar in some respects. Jurisdiction over minerals on Forest Service lands is moved to the Secretary of Agriculture. The concepts of "discovery" and "extralateral rights" are eliminated. A claimant is only given exclusive right of possession for mineral activities if a plan of operations, consistent with land-use plans, and financial guarantees for reclamation are submitted. Both bills require reclamation to premining site use. Mill site claims are eliminated. Patents are also eliminated, except where a patent application was filed before a certain date. Current claims or mill sites must be converted to the new system within 3 years. Both bills provide for user fees to recover administrative costs and establish a Hardrock Abandoned Mine Reclamation Fund, financed by fees or royalties, to address past mining damage. Virtually any citizen or noncitizen is given "standing" to sue the Secretary over noncompliance.

Significant differences exist between bills S. 433 and H.R. 918. Senate bill S. 433 provides for claims of up to 80 acres, establishes an incremental annual holding fee that is suspended on payment of royalties, imposes a 5% royalty on production, provides for surface use fees for mill sites, allows only 20 years to bring a mine into production, and requires biannual inspections by the land managing agency. House bill H.R. 918 limits claims to 40 acres, establishes annual rental fees (but no royalties) and incremental diligence expenditures or "in

lieu" payments, and requires quarterly inspections. Bill H.R. 2614 is similar to bill S. 433 in structure, but imposes an 8% royalty and bans foreign ownership of U.S. mines.

In striking a House provision to impose a fiscal year 1992 moratorium on patent issuance from the final fiscal year 1992 Interior Appropriations bill, H.R. 2686, it was agreed that the issues of fair market value of mining patents, a reversionary clause, and the holding fees would be taken up by the appropriate authorizing committee during fiscal year 1992.

On January 28, 1992, the American Mining Congress released an economic impact study of the Bumpers and Rahall reform bills prepared under contract by offices of Davis, Graham & Stubbs and Coopers & Lybrand, Denver, CO. The study concludes that annual fees and costs imposed on the mining industry would increase by more than \$120 million under S. 433 and by almost \$125 million under H.R. 918. The study asserts that as many as 30,000 jobs could be lost and reform could cost the Federal Government as much as \$230 million annually in lost revenue and increased spending. The study identifies annual holding/diligence expenditures as more than \$28 million under S. 433 and approximately \$100 million under H.R. 918 (fees minus credits). The latter amount approximates the Administration's projection for annual revenues to be generated by the \$100 holding fee.

The Bureau of Land Management Director testified in June 1991 "that the Administration opposes S. 433, H.R. 918, and any sweeping change of the discovery-location-patent system that has served us well." The Administration is said to be "committed to the retention of the four principles of the current Mining Law: (1) self-initiation of mineral rights, (2) free access across Federal lands, (3) security of tenure to mineral deposits, and (4) diligence that is self-policing." No statement has been made on bill H.R. 2614 by the Administration.

The mining industry concurred with the administration position and charged that complaints against the current mining

law were overstated and that the Bumpers and Rahall bills would have a devastating impact on domestic hard-rock mineral production. Industry concern focuses on loss of private tenure and project financing on significant holding costs and on new administrative expenses.

Clean Air Act Amendments (CAAA) 1990

The mining and minerals processing sectors will experience about an 11% compound annual growth rate for its direct capital expenditures for air pollution equipment over the next 3 years. Operating costs associated with this investment will increase, and those sectors that are sensitive to electrical energy costs will experience additional operating expense as the utilities pass through their added costs of compliance with acid rain provisions of the CAAA.

The air toxics provisions of the CAAA will impact mining and mineral processing in varied ways:

- (1) Existing coke oven batteries will have until January 1, 1998, to comply with emission standards by December 1992.
- (2) Heavy metals are prominent on the list of 189 hazardous substances to be regulated as air toxics. The mining companies have spent a good part of 1991 developing emissions characterization (a requirement for participation in the EPA's early reduction program).
- (3) Air toxics emitters will have to seek operating permits for the first time under the CAAA. The requirement to include public participation is in the legislation, but the degree of public participation and the magnitude of operational change that triggers public participation is still uncertain in the regulation.
- (4) The air toxics provisions also include a requirement to use risk assessment methods to assess human health risk after the best methods

have been replaced to meet standards. Risk assessment, as currently practiced, generally yields conservative risk estimates, which translate into greater costs.

The CAAA also mandated the EPA to study off-road diesel engine emissions, and the report has been issued. Mining interests are concerned that much of their equipment might be characterized as construction equipment (a troublesome category in the report) and thereby become initially subject to costly regulation.

Global warming from carbon dioxide (CO₂) and reconsideration of a short-term sulfur dioxide (SO₂) standard are two additional air pollution issues that have a potential for adding costs to mining and mineral processing.⁶

Lead-Acid Battery Recycling

Lead-acid battery recycling has increased in recent years. In 1989, the recycling rate was estimated to be 95%.⁷ Several factors have had a positive influence on the recycling rate: (1) battery recycling laws have been enacted by 33 States in the past several years, (2) the development of a multipath system to collect and recycle lead-acid batteries, (3) scrapped battery buyback programs at some stores have encouraged consumers to turn in their old batteries, (4) a growing public awareness of the potential environmental impacts that could result from batteries that are not recycled, and (5) an increase in the price of lead scrap.

Federal legislation related to the recycling of lead-acid batteries was introduced in the 101st Congress but was not acted upon. The "Lead Battery Recycling Incentives Act" bill, H.R. 870, and a comparable bill, S. 398, were introduced into the 102d Congress. These basically identical bills would require manufacturers and importers of lead-acid batteries to use a minimum amount of recycled lead in the batteries they produce. Domestic battery producers and importers who do not use recycled lead could be required to purchase credits from others who recycle batteries. Bill

S. 392, introduced in 1991, sets maximum lead content on certain products and prohibits the disposal of lead-acid batteries in landfills and incinerators. Legislation was also introduced (H.R. 2922) that would tax primary lead production at \$0.75/lb and secondary production at \$0.37/lb to pay for a \$1 billion trust fund for a lead abatement project.

In 1991, the EPA initiated a regulatory negotiation for a battery recycling rule. The regulatory negotiation was established under the Federal Advisory Committee Act (FACA). The committee negotiated issues to regulate the recycling of lead-acid batteries under section 6 of the TSCA. After 10 months, the regulatory negotiation came to an abrupt end when EPA officials announced that the costs associated with a Federal rule would outweigh any benefits it might promote.

The Doe Run Co. is completing the engineering phase of its \$38 million lead-acid battery recycling center in Boss, MO, and is gearing for a September 1992 opening. The facility is projected to produce as much as 60,000 tons of refined lead each year from 120,000 tons of used automobile materials. The facility will use a process that produces about one-third the volume of hazardous waste normally associated with battery recycling operations.⁸

Basel Convention

In March 1990, the United States signed the Basel Convention, an international agreement that deals with the international transboundary movement of hazardous waste. The Basel Convention is intended to put an end to the shipment of hazardous wastes for disposal in other nations, particularly Third World or developing nations. However, the convention agreement could affect the way metal waste and scrap, as well as other recyclable materials, are imported or exported as all of these materials are considered to be hazardous wastes in some countries, particularly within the European Community. Materials that are likely to be affected include, but are not

limited to, materials recovered from municipal waste, metal waste and scrap, precious-metal wastes and residues, and scrap batteries.

Under the Basel Convention, requirements will include advance notification of shipments of hazardous wastes through the Governments of the exporting and importing nations. Both the exporting and importing nations are obliged to ensure that the handling and disposal of the waste is environmentally sound. Trade in hazardous waste between a nation that is a party to the convention and one that is not will be prohibited, unless the nations enter into a separate agreement that is at least as protective of the environment as is the Basel Convention.

The Basel Treaty was submitted to the Senate on May 20, 1991. Legislation was introduced to provide the authority to implement the terms of the treaty in the United States. The Senate has not ratified the agreement, but it appears likely that the necessary signatures from 20 other countries will occur in early 1992.

Trade Issues

Canada, Mexico, and the United States began the negotiation of the North American Free Trade Agreement (NAFTA) in June 1991. In the NAFTA, the United States is seeking enhanced market access for goods and services, clarification of the rules governing trade and investment, enhanced intellectual property protection, and an effective mechanism for the settlement of trade and investment disputes. Mexico currently prohibits majority foreign ownership of mines, while the United States maintains no similar restrictions against foreign mineral investment. As of early spring 1992, the negotiations had advanced substantially, but no completion date for the talks had been established.

General Agreement of Tariffs and Trade (GATT) talks resumed in September 1991 in Geneva. In the middle of the Uruguay Round of tariff negotiations, countries, including Australia, Canada, and the United States,

are ready to adopt zero-for-zero tariffs for all nonferrous metals. Other countries are maintaining protective stances for certain metal industries. For example, France opposes any lessening of its 10% tariff on semifabricated aluminum products, while Japan continues to resist dropping tariffs on copper. Negotiators say that all nonferrous metals are being considered for zero-for-zero treatment. Although talks are still in the exploratory stage, it appears that it will not be possible to eliminate all such tariffs. The successful completion of these negotiations depends on resolution of the complex agricultural issues, on which only limited progress was reported during the year.⁹

Public Land Use

A U.S. Bureau of Mines report about potential mineral impacts of California desert land use bills is available. The report, Economic Analysis of the Minerals Potential of the East Mojave National Scenic Area (EMNSA), CA (OFR 55-92 and 56-92), covers both known mineral resources and the undiscovered metals potential of the 1.5-million-acre EMNSA. The report shows how the economic potential of these minerals would be affected under two proposals. One proposal, passed by the House in November 1991 as H.R. 2929, would change the land use management of many areas of the desert and would convert EMNSA into a national monument, similar to a park. Mining, except already developed sites, would be precluded from the area by this proposal. As an alternative, the Administration has proposed wilderness designation for several areas inside and outside EMNSA. Bill S. 21 was reintroduced at the start of the second session of the 102d Congress. The Administration's alternative bill, S. 2393, was also submitted and follows the recommendations of the BLM.

National Defense Stockpile

During 1991 the Department of Defense reviewed its stockpile needs. It asked Congress to hold off on authorizing

purchases that included 4.42 million lbs of tantalum, 15.8 million lbs of columbium, and \$1.7 billion in disposals until the Agency finishes a review of potential world threats and changes now taking place in Eastern Europe, the Middle East, and the new C.I.S. The Department may plan the stockpile according to a 1-year war scenario rather than a 3-year war. A fall report Defense to Congress on NDS requirements recommended the stockpile contain metals and materials worth a total of about \$5.6 billion rather than the \$7.3 billion it currently holds.¹⁰

EXPLORATION

International Overview

As 1991 began, world attention was focused on the Near East and the crisis caused by Iraq's invasion of Kuwait in 1990. The possibilities of a protracted war and of a major curtailment in global crude oil supplies, and consequent impact on world industrial activity, loomed large in the minds of many. The brevity and effectiveness of "Desert Storm" in restoring control of Kuwait to its lawful Government served to confine the impact of the episode on global mineral industry performance chiefly to Iraq's destruction of Kuwait's oil facilities and embargoes on Iraqi trade in oil and sulfur. There were also negative effects on mineral industry activities in other Near Eastern countries, especially resulting from transportation difficulties, as with Jordanian phosphates and potash.

The trade sanctions and the war disrupted trade between Turkey and its neighbors, particularly affecting Turkish steel exports and oil imports from Iraq. Balance of trade losses in 1990 and early 1991 may be offset by gains that may result from the war. Turkish steel, cement, other mineral materials, and labor forces may find ready markets in the rebuilding in Kuwait and Iraq.

Another possible benefit of the conflict is the chance for moderation of the Arab-Israeli conflict that has deterred investment in the area for decades. As the year ended, the U.S.-backed regional

peace talks offered hope for resolution of this issue.

Probably the single most notable trend in global mineral industry operations in 1991 was an overall move toward privatization. Shifts continued toward market economy operations in Central and Eastern European countries, and similar changes were developing within the C.I.S. More significantly, however, several countries with recent track records of nationalizing mineral operations reversed their directions. This trend was evidenced in the market economies of Western European, Latin American, African, and Asian countries.

For the countries of Eastern Europe that began this trend, the 1990 euphoria over economic and political freedom was tempered in 1991 by the realization that rationalization of inefficient industries would prove a painful process and that a sudden leap to total market economy doctrines was unrealistic. In most of these countries, 1991 output cutbacks reflected rationalization, but at a slower rate than had been expected. Using steel industry output as a measure, Czechoslovakian output in the first 5 months was only 2.2% below that of the last 5 months of 1990; Poland logged an 8% reduction in the same months, and Hungary registered a 10.6% drop. Although precisely comparable data were not available for Bulgaria and Romania, declines of about 20% to 30% could be realized.

A major pitfall to privatization in these countries is the inefficient nature of present operations that deters private investment. The physical plants are generally outmoded, environmentally unsound, and inefficient. Also, the nature and level of the work force must be considered. To reduce work forces to reasonable levels for economic operations would mean layoffs that would be unacceptable to the central Governments. The commitment to change remains in place, but the rate of change probably will be slower than originally intended. A newsworthy symptom of the difficulties experienced was the massive protests of conditions by Romanian coal industry personnel, who virtually laid siege to

Government offices in Bucharest that were quelled only by the use of force.

The year 1991 has been a painful one for the C.I.S. The separation of the Baltic Republics had only very modest direct impact on mineral industry operations, but it seemed to set the pattern for the demise of the U.S.S.R. as it has existed for 70 years and for the emergence of the remaining Republics as largely independent entities. This had a major effect on mineral industry operations. Central control of ventures was declining without emergence of any mechanism to replace it, and the coup attempt in August 1991 intensified the process of change toward control by the individual Republics.

Under the economic treaty prepared by the central Government late in the year and signed by a number of the constituent Republics, these Republics were to have sovereignty over their natural resources and have responsibility for their management. Even with these significant shifts, not all Republics signed the treaty.

Under these conditions, Soviet output of many mineral commodities fell. Steel output in the first 5 months of 1991 was 6.3% below the output for the last 5 months of 1990; cement output was down by 3% when compared to the same periods; and coal production, essential for almost all other industrial activity, was 10% below that of late 1990.

Within Western Europe, most activity was in the Federal Republic of Germany, where economic, environmental, and social pressures from unification were reflected in diminished mineral industry output in the Eastern states. The European Community moved toward a somewhat higher level of crude mineral supply self-sufficiency with expansion of output at the Neves-Corvo copper-tin operation in Portugal and the addition of the East German states. Steps toward further privatization of mineral industry operations were seen in France, Norway, the United Kingdom, and others.

In the Western Hemisphere, the overall Canadian economy was in a recession, and this, coupled with the economic situation in the United States, impacted upon Canada's mineral industry. A

strong U.S. economy is vital for Canada's mineral industry, for in normal times, about 75% of Canadian mineral exports is destined for the United States. The separatist movement in Quebec Province and environmental concerns exacerbated economic problems for the country's mineral industry.

In Latin America, a number of countries showed general economic rebounds to pre-1990 levels, with indications of stronger performances by Argentina, Chile, Colombia, Mexico, and Venezuela, among the larger countries. A significant contribution to these gains, however, was from the petroleum industries of the countries, and an overall upturn in nonfuel mineral operations was not so evident. Chile's copper industry made significant progress as the Escondida Mine was inaugurated. Through midyear, Peru seemed to be edging upward again in output of its major nonferrous metals after a disastrous 1990. In Mexico, of the major nonferrous metals, only zinc output was running ahead of 1990 levels at midyear. A Brazilian official predicted that 1991 output in that country's mineral sector would decrease except for output of iron ore.

Latin America as a whole was moving measurably back toward private enterprise, with official policies established in Argentina, Brazil, Chile, Costa Rica, Honduras, Mexico, Nicaragua, Peru, Uruguay, and Venezuela. Sale of Government equity in Mexico's La Caridad and Cananea copper operations in 1988 and 1990, respectively, was followed with similar actions in the steel industry and manganese and coal mining. Argentina and Brazil planned to sell government-owned steel mills, and Nicaragua announced its intention to sell three nationalized gold mines. The general economy of Nicaragua registered a gain for the first time in 8 years, after the governmental change.

A trend toward free trade agreements among Western Hemisphere countries seemed to be developing and could have implications for the mineral industry. Mexico was seeking a linkage with the

United States and Canada by early 1992. Similar linkages were sought by other groups of countries, including Argentina, Brazil, Paraguay, and Uruguay (The Southern Cone Common Market), Bolivia, Colombia, Ecuador, Peru, and Venezuela (an Andean Free Trade Zone), and 13 English-speaking Caribbean nations.

On the African continent, political changes in the Republic of South Africa led to removal of most international economic sanctions, brightening the prospects for mineral industry development. The country is a mineral-rich area most noted for its production of chromite, diamond, gold, manganese, platinum, and uranium. The agreement of the vast majority of South African political parties to the September National Peace Accord provided much hope for progress toward internal stability, but this accord will not be a panacea for all problems. The Republic's shift from apartheid will permit improved relations with other African states, thereby providing the opportunity for financial and technical assistance to the minerals sectors of these countries.

Elsewhere in Africa, political changes occurred that could bode well for mineral industry development. In Nigeria, the military government announced plans to install a civilian government in 1992. Already, reform programs to replace the state-run economy with a market economy have been implemented. In Zimbabwe, the lifting of the state of emergency in place for 25 years and implementation of a trade liberalization program aimed at export-oriented economic sectors were expected to improve the country's image as an investment site. In Ghana, the Government continued privatization efforts, finding buyers for a formerly Government-owned gold mine and a diamond mine.

Even in Liberia, where civil war closed the nation's two iron mines in 1990, there appeared to be prospects for a return to stability. One iron mine reopened in 1991, but there was no target reopening date for the other, and no

evidence of renewed exploration for gold and diamonds.

In Angola, finalization of peace accords in May 1991 terminated that country's multiyear civil war. This, and promise of multiparty elections in 1992, brightened the outlook for foreign investment, not only in Angola's mineral resources, but also in rail links through that country from its port to major mineral producers, Zaire and Zambia.

On the negative side, Zaire, a major copper and diamond producer and premier source of cobalt, suffered riots in its copper-producing area in 1991 that led to the flight of the expatriate technical staff. This, along with a major copper-cobalt mine cave-in, shortages of fuel and spare parts for mining equipment, and a host of managerial and political problems, led to a downturn in output of copper and cobalt and to a negative climate for investment. By early November, the cobalt shortfall increased prices to more than \$30 per pound.

In Asia, the continued growth of Japan's economy was reflected in record levels of steel and cement output and increasing consumption levels for most major nonferrous metals, at least through midyear. Output and usage of other mineral commodities presumably advanced as well.

China continued efforts to improve its nonferrous metals supply position, long a weak point. The steel industry was striving for greater production of high-quality steel while continuing expansion of total production. The legacy of Tiananmen Square, however, continued as an obstacle to increasing international involvement. The question of Chinese barriers to U.S. exports to China was raised in the United States as another reason for restricting imports from China due to the growing trade balance between the two nations. Another issue was the marketing of Chinese commodities, such as tungsten, at less than fair value.

The steel industries of the Republic of Korea and Taiwan continued to grow, marking their progress toward developed nation status, and these areas, as well as others such as Indonesia and Thailand,

continued expansion and diversification in overall mineral industry activities. The Philippines continued to experience economic difficulties that were reflected in mineral industry performance. Burma, with its authoritarian regime and civil strife, remained unlikely to receive significant foreign investment capital in mineral ventures.

Among the countries in the Pacific, Australia continued in its role as a major world supplier of bauxite, copper, diamond, iron ore, lead, and zinc, to cite but a few major commodities. Other notable Pacific mineral producers were Papua New Guinea, with copper, gold, and silver, and New Caledonia, with its lateritic nickel deposits.

Domestic Overview

The Society of Economic Geologists (SEG) conducts an annual Mineral Exploration Statistics Survey with financial support from the U.S. Bureau of Mines and the U.S. Geological Survey. The SEG survey gauges the levels of current international hard-rock mineral exploration by Canadian and U.S. companies. Based on 1990 survey responses from 29 United States and 26 Canadian companies operating in the United States, results show that the average corporate exploration budget increased over 1989 levels with the bulk of the funds still going to base metals and precious-metals targets. However, a contraction of the industry resulted in overall exploration expenditures remaining flat in 1990 with only a 1% increase over 1989 to \$164 million. Reported uranium budgets were at one-half of their prior year levels while industrial mineral programs were on the rise.

Base metals and precious-metals exploration in the United States during 1990 appeared to be growing, but only among those companies still maintaining exploration programs. The total number of companies involved in U.S. exploration continued to dwindle. Epithermal gold deposits were the primary focus of this exploration, although certain copper and zinc deposit

types were also sought. While most known U.S. porphyry copper deposits were owned by the large copper producers, companies were revisiting skarn targets because of the successful discoveries of large gold resources in Nevada and Washington. Positive results received at "porphyry-gold" targets in the Northwest and Alaska also attracted many companies. Although exploration for industrial minerals and uranium was at subordinate levels, a recent surge in acquisition of known U.S. uranium reserves is under way.

A shift in exploration spending appeared to have occurred between 1989 and 1990. Significant increases in the cost of administrative activities (5.6% of total budget) were measured, while field activities, such as geologic and geochemistry studies, prospecting, and drilling declined, by 2% to 4%. An increase in geophysical activities was also noted, which may reflect a returning interest in base metal targets as well as an increase in gold exploration. Overall, the numbers implied that, for companies with fixed exploration budgets, administrative costs increased at the expense of fieldwork.

A change in the composition of exploration staffs was also reported over the 1989-90 period. A sharp drop in the use of summer students was offset by a rise in the use of professional consultants. Also, a net increase in exploration staffs, mainly in the administrative and support category, was reported. This, along with higher reported administrative costs, may reflect the need to meet increasing environmental and regulatory compliance requirements.

Research by Balfour Holdings, used by the SEG to supplement survey results, indicates that more than 130 Canadian and 50 United States mineral firms, representing essentially all of the senior- and middle-tier metal producers, were operating in or establishing offices in Latin America. This rush to Latin America may reflect the following:

- (1) A perception that most of the large mineral deposits in the contiguous United States and Canada have been

developed and the acquisition market is saturated;

- (2) Improved foreign investment climate in many Latin America countries;
- (3) Increased environmental costs and permitting delays in bringing a new mine on-stream in the United States;
- (4) A perception that proposed reform of the General Mining Law of 1872 will substantially increase the holding cost and investment risk per exploration acre; and
- (5) Additional taxes and fees imposed or being considered at the State level.

If metal prices continue to stay relatively low, these factors could fuel a substantial deterioration in the number of companies willing to or financially able to develop the Nation's mineral resources.

DEVELOPMENT

Code of Federal Regulations— Implications for Mine Development

Leasing of Osage Reservation Lands for Mining for Minerals Other Than Oil and Gas.—The Bureau of Indian Affairs (BIA) is proposing to revise the regulations in 25 CFR 214 governing management of non-oil and gas minerals on Osage Reservation Lands in Oklahoma. The proposed revision eliminates specific royalties for minerals not found within the Osage Minerals estate and gives authority to the Osage Tribal Council, with the approval of the Superintendent of the Osage Agency, to set applicable royalty rates. This revision also replaces outmoded methods of exchange with modern methods and correctly designates those officials responsible for the management of non-oil and gas minerals within the Osage Mineral estate. The proposed revisions are intended to enhance the management ability of the Department over the production of these minerals and to

eliminate various inaccuracies in the current regulations.¹¹

Lead and Zinc Mining Operations, Quapaw Agency.—BIA proposes to amend 25 CFR 215 to update the operations and procedures for leasing, discovering, testing, and processing lead and zinc minerals on lands under the jurisdiction of the Bureau's Miami Agency in Ottawa County, OK. Current regulations governing such leases were developed more than 30 years ago and no longer reflect current practices or standards in the mining industry. The proposed revisions will assist affected Indians with the efficient development of their lead and zinc deposits without waste, avoidable loss, or damage to their natural resources, the environment, or other resources. The Bureau also proposes to retitle 25 CFR 215 as "Lead and Zinc Mining Operations and Leases, Miami Agency."¹²

Leasing of Certain Lands on the Wind River Indian Reservation, Wyoming, for Oil and Gas Mining.—The regulations of 24 CFR 227 are being revised to reflect organizational changes in the BIA and BLM. The principal changes update the reference to the BLM official assigned various responsibilities by the regulations.¹³

Geological and Geophysical Exploration of the Outer Continental Shelf.—The rule is revised to reflect the current requirements and practices and to conform with new or changed laws and regulations. It expands the requirements for filing notice to include all geological and geophysical research not conducted pursuant to a permit. It clarifies that those regulations are applicable only to oil, gas, and sulfur, as all other mineral resources on the Outer Continental Shelf are covered by 30 CFR Part 280. This rule will provide other pertinent information, such as current filing location addresses.¹⁴

Abandoned Mine Land Reclamation Fund Reauthorization.—Pursuant to the

recently enacted Abandoned Mine Reclamation Act of 1990, the regulations found in 30 CFR Subchapter R require revision and amendment to reflect and implement the new provisions contained in the statute. The subject provisions address the eligibility of both coal and noncoal reclamation projects and also relate to the collection and allocation of abandoned mine land fees to eligible reclamation projects, including the Rural Abandoned Mine Program and the Small Operator Assistance Program.¹⁵

Mining Claims Under the General Mining Laws.—This rule will require submission of financial guarantees for reclamation for all mining operations greater than casual use, create additional financial instruments for the purpose, and require operators with a record of noncompliance to file plans of operations.¹⁶

Mining in Military Withdrawals.—This proposed rule establishes guidelines for mining in certain military installations under the Mining Law of 1872, as amended, and unimpeded use of the lands for military purposes. The Military Lands Withdrawal Act of 1986 specifically provided for certain military lands previously withdrawn from mining to be considered for opening to the operation of the Mining Law of 1872, as amended, with certain special restrictions. Mining Lands identified as suitable for mining through the BLM's planning system are proposed to be opened on the effective date of an opening order that will be published in the Federal Register.¹⁷

Mining Claims Under the General Mining Law—Nature and Classes of Mining Claims Assessment Work.—This rulemaking will amend the existing regulations to include the criteria for the standard of discovery as applied to oil shale placer mining claims and provide clarification of what constitutes substantial compliance with assessment work requirements under the mining law.¹⁸

UNDERGROUND MINING

Coal Extraction Equipment

Continuous Mining.—A new addition to the Voest Alpine line is the Alpine Miner AM 85,¹⁹ a further development of the AM 75. Among its particular features is an increase of 30% in the sumping-in force when using the telescopic forward feed system, compared with conventional sumping through crawler advance. The telescopic forward feed system also minimizes ribs in the floor and roof.

The forward feed system allows the movement of the entire machine body, including loading table and chain conveyor relative to the track frames and the rear stabilizer. This feature enables the unit to sump smoothly and steadily even when poor floor conditions are encountered. The cutter motor is built into a carrier rather than being self supporting. The cutter transmission with the cutter head is directly flanged onto the motor carrier. This allows exchange of the cutting motor without the need to remove the cutter transmission and cutter heads.²⁰

Ingersoll-Rand, in conjunction with sister company Simmons-Rand, recently delivered a new LN-800 3TT continuous miner to Cape Breton Development Corp. for the Lingan Phalen Mine in Nova Scotia. The order followed the successful performance of a fleet of 15 LN-800 miners in the Selby coalfield, United Kingdom.

The LN-800 series was developed to meet the exacting requirements of British Coal and, according to Ingersoll-Rand, is now the best selling series of continuous miners in the British coalfields. The flexible mining capability ranges from seams as low as 4.5 feet (ft) to high seams as high as 12 ft. The full modular design of the LN-800 3TT is based on a four-piece chassis and two-piece conveyor/boom, facilitating easier movement underground.²¹

Joy Technologies and its global manufacturing companies in Australia, Republic of South Africa, and the United

Kingdom have introduced the 12CM20 Mk2 continuous miner fitted with four hydraulic roof bolters immediately behind an east-west conveyor. The machine has all-gear traction drive and has been designed to give low ground-bearing pressure, which improves maneuverability and lowers cycle times. Three such machines are now operating in Australia and Republic of South Africa.²²

Longwall Shearers.—British Coal has won a Queen's Award for Technological Achievement for its shearer Extraction Drum. The Extraction Drum has been under development for 10 years and became standard equipment on coal faces throughout Britain in 1987. It is the first device to successfully control both dust and ignitions at the coal face.

Underground measurements have shown reductions in respirable dust on the coal face of 80% compared with drums fitted with standard water sprays. Instances of face ignitions are down more than 50%, and pneumoconiosis, which affected 10% of the miners as recently as 1970, has been reduced to the lowest level in the history of coal mining, 0.7%.²³

The 6LS is Joy's most powerful shearer with an installed power of 1,120 kilowatts (kW) and the ability to mine seam thicknesses up to 14.8 ft. Six of these multimotor electric haulage units have been sold with good operational results. The combined tonnages of the first two machines exceeded 3.35 million tons in less than 9 months.

One of SAGEM's latest installations is a Panda single-drum shearer for the Warndt Mine in Germany. It is designed to cut an 18.4-ft-thick seam along a 985-ft longwall face at gradients exceeding 50%, which SAGEM claims is a world first. It cuts the seam, drum fully engaged, when moving from the bottom to the top of the face, and the same in reverse.

The mounting height is 7.6 ft above the floor, and the unit is equipped with an 8.2-ft cutting drum. The main motor power is 500 kW, continuous rating. The haulage pull is 40 tons, and the haulage speed is up to 35 feet per minute (ft/min).

The first of three recent longwall installations of interest supplied by Eickhoff is an EDW-230-2L-2W with Eicotrack, Eickhoff's chainless haulage system, at the Prosper-Haniel Mine in Germany. This machine is powered by two water-cooled 230-kW motors that are mounted directly on the ranging arms. This results in a short machine length in comparison with conventional shearers of the same rating.²⁴

In the United States, Westmoreland Coal's EDW-300-LN shearer loader, a new development for thin seams, is extremely short, but with its motor rating of 335 kW, is particularly powerful. The full power of 300 kW can be transmitted to the leading drum. This double-ended ranging drum shearer is equipped with electric haulage units and travels alongside the conveyor. A bridge to which the machine body is mounted straddles the face conveyor. If the Eicotrack system is positioned on the face side, the shearer is guided by a tube, and if it is on the gob side the Eicotrack rack bars serve as a guide.

The popularity of Anderson Longwall's Electra series continues to grow. This range of multimotor shearers is capable of working in seam sections from 40 to 235 inches (in) and can be supplied with power outputs from 375 to 1,200 kW. This year saw further Electra installations in Australia, France, Poland, United Kingdom, and the United States.

Machines for France and the United States both broke new ground. In the United States, the new Thin Seam Electra can mine down to 39 in. The shearer has various features unique to the thin-seam version, which allows for higher powers, greater reliability, easier maintenance, and safer operation. The Electra 2000 in France features installed power of 1,200 kW and operates at 5.5 kilovolts (kV). Each ranging arm motor is rated at 450 kW.²⁵

Longwall Supports.—In the United States, Gullick Dobson recently supplied equipment for a 15.6-ft-high longwall. The two-leg, 604-ton supports have a closed height for transportation of 6 ft and a hydraulic range of 7 to 16 ft. The

installation will be controlled using Gullick's Electroflex Machine Initiation System. Gullick claims that Electroflex, which incorporates motorized valves in place of the more traditional solenoid type, is becoming widely accepted as the most successful system to incorporate Shearer Machine Initiation.

The Bilsthorpe Mine is British Coal's first full-face longwall with heavy-duty two-leg supports. The electronically controlled immediate forward support chocks, with a yield of 510 tons, are being installed on the mine's first retreat face. The supports, manufactured by Mecco International, will be operated with the main hydraulic supply at 4,000 pounds per square inch (psi).

The largest two-leg supports in the world, with an 880-ton capacity, are being installed by Gullick Dobson at Australia's largest underground mine, the Gordonstone Mine.²⁶

Hard-Rock Equipment

Drilling.—A test program was conducted in a hard-rock mine in Sudbury, Ontario, to investigate dry drilling in underground bulk mining as potentially faster and more economical than wet drilling. The results indicate that penetration rates can be increased by approximately 24% by drilling with mine air as compared with wet drilling under the same circumstances. Bit life is reported to be substantially increased when drilling dry. An economic analysis for typical hard-rock drilling indicated that drilling productivity and cost savings can be increased by about 23% when dry drilling is used.

Dry drilling is usually shunned underground because of unacceptable levels of dust. The researchers wanted to know whether or not dry drilling provides enough increases in productivity and savings in drill costs to warrant the development or adaptation of dust control technology for use underground.²⁷

Corwall, United Kingdom-based CompAir Holman, has introduced a new generation crawler drill rig, the Unitrak. The Unitrak is capable of both vertical and horizontal drilling in confined spaces.

A versatile machine, its launch follows the success of the original M-Trak, CompAir Holman's successful crawler-mounted compact drill rig.

The Unitrak can drill vertical holes of up to 11.8-in diameter to a depth of 50 ft, and with a suitable compressor, can utilize up to 7.9 in DTH hammers. Like the M-Trak, the new drill rig is suited to methane extraction, site investigations, test boring, and other tasks. By hydraulically tilting the drill mast incorporating rotation and feed motors through a 90° angle, the Unitrak can carry out horizontal drilling, including rock bolting and grouting for tunnel wall cliff reinforcement.²⁸

Atlas Copco has introduced a new series of Boltec, fully mechanized rock bolting rigs, that are claimed to increase productivity in rock bolting by an average of 20%. These rigs can be used to install all types of rock bolts commonly used in mining. The main development is a compact single-feed drilling-bolting unit. A simple switch-over arrangement permits the operator to change from drilling to bolting without moving the feed from the hole position. The advantage is obvious: the bolt never misses the hole. It also gives the operator full visibility of the operation. The concept requires less space, is easier and faster to maneuver, and allows greater precision and accessibility. The improvement in stability of units having two heavy steel feeds is the direct result of the reduced swinging mass.

Uneven rock surfaces often prevent the rock bolts from being installed to their full length when using a mechanized bolting rig. The new Boltec unit permits all holes to be drilled to the full depth and proper installation of rock bolts in the most uneven conditions. The swing-away drill-steel support opens automatically to permit the rock drill and the bolt, respectively, to pass, utilizing the full length of the feed. The bolt magazine is mounted low and out of the way to avoid interference with uneven rock surfaces.²⁹

Water-Jet-Assisted Cutting.—The U.S. Department of Energy (DOE) has a cooperative agreement with Alpine

Equipment Co. to evaluate the water-jet-assisted mechanical cutting of oil shale. A concurrent goal of this project has been to determine the effectiveness of polycrystalline diamond composite (PCD) bits in cutting oil shale and the possible synergy of these bits and water-jet-assisted cutting.

PCD is about 300 times as wear resistant as carbide, making it an ideal cutting tool. The PCD cutter consists of a thin layer—0.01 to 0.04 in—of polycrystalline diamond integrally sintered at ultrahigh pressure and temperature to a cemented tungsten carbide substrate. Tests have shown convincingly that the potential for this technology is considerable. Experience with rotary PCD drill bits in the Unical oil shale mine in Colorado has shown that these cost about 10 times more than conventional carbide bits, but have a life expectancy of about 80 times longer. In this way, the combination of water-jet-assist and PCD bits may represent the first major advance in hard-rock cutting technology since the introduction of tungsten carbide tools 40 years ago.³⁰

Haulage.—A new underground truck designed primarily for transporting rock but able to carry out other essential tasks has been introduced by John Clark, Inc., (JCI) Denver, CO. The main feature of its design is the use of multiple containers or modules that can be interchanged, thus resulting in lower operating and capital costs than with conventional LHD or truck haulage. The JCI C1504, the 15-ton container truck, is a low profile, center articulated rear dump that allows one container to be loaded while another is being trammed to the dump.³¹

After almost 2 years of development, Getman Corp. has introduced the model RDG-1504C underground road builder for hard-rock mines. The machine is designed to eliminate the high maintenance cost of modified, lighter class vehicles currently in use. The unit is also meant to provide long life and high performance at a competitive price.

Graders offer advantages over other types of machinery used for servicing roadways that have been rolled or

compacted. After treatment with a grader, the road surface is left cleaner and harder. Remaining material is smooth and solid, not compacted and crushed and able to be loosened by continuous traffic. As a result of grader treatment, savings on vehicular wear from shock loading will be realized. In addition, vehicle life will be longer and downtime will be less.³²

DOE's Nuclear Waste Repository

Some scientists and environmental groups are pressing the DOE to abandon plans for a nuclear waste repository at Nevada's Yucca Mountain and to start searching for a site with more stable ground conditions. Critics of the Yucca Mountain site believe geological conditions surrounding the proposed repository are too unpredictable. They do not believe the repository can remain leak-free for the expected 10,000 years.

DOE is expected to spend \$4 billion studying the geological conditions of Yucca Mountain and another \$15 billion developing the repository over the next 20 years. The repository will house high-level radioactive waste from the Nation's military operations and industrial plants. DOE and the U.S. Geological Survey (USGS), which is leading the Yucca Mountain study, acknowledge that more study on Yucca Mountain's ground conditions is needed before it can be declared a suitable site. Results from drilling deep test holes to find water pockets above the known water table have been favorable.³³

Raise Boring at Craig Mine

The third of four 4,000-ft-long vent raises is in the final reaming stage at Falconbridge Ltd.'s new Craig Mine in the Sudbury district, Ontario. The raise is being bored by Redpath Raise-Boring Ltd. using one of the most powerful raise drills in existence, a 400-horsepower (hp) Robbins 97RL-DC belonging to Falconbridge.

Final diameter of all of the vent raises is 10 to 12 ft. The first two raises, one intake and one exhaust, were completed

in 1989 and 1990. The present one, an exhaust raise, will be finished in 1991. A fourth 12-ft-diameter exhaust raise will be drilled in 1993, which, combined with the service shaft (air intake), will complete the Craig Mine's ventilation system. Each of these vent raises really consists of two separate raises, making eight in all. Together, they will total more than 16,000 ft in length and are some of the largest and longest raises ever to be bored in Canada.³⁴

Rock Stress Measurement

Mining engineers recognize that the design of the safest and most cost-effective excavations underground depends on the accurate measurement of the magnitude and direction of rock stress fields.

There are two main methods of measuring rock stress, overcoring and hydrofracture. Commonwealth Scientific and Industrial Research Organization's (CSIRO) Division of Geomechanics has investigated and applied hydraulic fracturing techniques over the past 15 years and is considered to be a world leader in rock stress measurement. The Minifrac system has evolved from this research as a portable kit for rock stress measurements from small diameter boreholes of up to 98 ft long and has now been fully developed and tested at a number of underground engineering sites in Australia.

The system has generated considerable interest from Australia and overseas during its development; the first customer outside Australia was British Coal at Bretby. British Coal researchers are testing its suitability for quick, exploratory stress estimations before more accurate methods are used, such as overcoring, which is the normal technique.³⁵

Solid-Woven Conveyor Belts

The solid-woven conveyor belting concept was developed for underground coal mining. In many countries, it has replaced the traditional multi-ply and steel-cord constructions. It is now

making inroads into the aboveground market, in short- and long-haul installations where tear and impact resistance are particularly appreciated.

Steel-cord belts were traditionally used on long-haul installations and have shown their worth in hundreds of cases. However, they do have shortcomings. The steel cords can corrode and will do so more rapidly depending on the corrosiveness of the product they are carrying or the environment in which they are used.

Solid-woven construction consists of a fully interconnected structure with a high density of ultrastrong monofilament synthetic yarns both in the warp and the weft directions. The outer layers contain spun, synthetic yarns for additional impact protection and the whole is fully impregnated with polyvinyl chloride (PVC) to form a composite with exceptional tear resistance in the longitudinal and the transverse directions. The measured test according to tear strength of solid-woven belts is as much as 300% higher than correspondingly rated multi-ply belts and many times greater still than woven steel or breaker reinforced steel cord constructions.³⁶

SURFACE MINING

In 1991, gold continued its trend as the most sought after commodity. Several new metal mines came on-line, and some notable milestones were achieved by both domestic and foreign producers.

South Carolina's fourth gold mine began operation in early 1991. The new open pit, heap-leaching operation, known as the Barite Hill Mine, is near McCormick, SC, about 30 miles north of Augusta, GA. Company officials expect the Barite Hill to yield about 20,500 troy ounces per year (tr oz/yr) of gold and 61,500 tr oz/yr of silver. Barite Hill was developed by Gwalia (U.S.A.) Ltd., a subsidiary of Gwalia International Ltd. of Perth, Western Australia, and is centered around several long-abandoned gold mines, including the old Dorn Mine, which produced gold between the 1850's and 1930's.

New Zealand's second lode gold mine, the Macraes Mine, recently commenced production. The new open pit operation, wholly owned by Macraes Mining Co. Ltd., is in the Otago region about 37 miles north of Dunedin on New Zealand's South Island. Gold production during the first year of operation is expected to exceed 55,000 tr oz/yr and amount to almost 90,000 tr oz/yr thereafter. Ore reserves at the Macraes are reportedly sufficient to sustain operations for at least 10 years.³⁷

North America's largest gold mine, The Gold Quarry Mine, has produced a record 1 million troy ounces (tr oz) of gold in the year to December 22, 1991. The mine, which is owned and operated by Newmont Gold Co., produced 939,800 tr oz of gold in 1990 and is expected to produce almost 1 million tr oz of gold in 1992. The mine was commissioned in 1985 and produced 106,500 tr oz of gold that year. At the end of 1990, the mine contained 8.9 million tr oz of proven and probable reserves.³⁸

Channar is the first new iron ore mine in Australia in 15 years and the first overseas mining project in which China has taken a direct equity interest. Channar is a joint venture between a wholly owned subsidiary of Hamersley Holdings Ltd. (60%) and the China Metallurgical Import and Export Corp. (40%). The mine will supply approximately 220 million st of high-grade iron ore to China for a period of 20 years—3.3 million short tons per year (st/yr) in the first year of operation, rising to 11 million st/yr by 1997. Iron ore is mined from five major ore bodies approximately 12.4 miles east of Hamersley Iron's Paraburdoo Mine. Operations started in 1990, and the first year's production was on schedule with 6.6 million st being moved to provide 3.4 million st of crusher product. Production of crusher product in 1991 should rise to 6.1 million st.³⁹

A major vanadium mine is to be brought on-line by Precious Metals Australia (PMA). The Windimurra project will be Australia's first vanadium mine and is expected to be producing

4,070 st/yr vanadium pentoxide by the end of 1992. Windimurra is in the Murchison District of Western Australia, about 37 miles from the Youanmi Gold Mine, which the directors of PMA brought into production a few years ago. The vanadium potential of the district has been known for many years. PMA controls 244 square miles (mi²) of the deposit, which is approximately 230 ft wide and outcrops as a low ridge about 16 m in length. Proven reserves are 16.5 million st of vanadiferous titanomagnetite, but the probable resource could be as much as 110 million st. Vanadium is present in solid solution in the magnetite.⁴⁰

Arco Coal's Black Thunder Mine, near Wright, WY, celebrated the shipment of its first 250 million st of coal. Black Thunder is the Nation's largest producing coal mine. Mine employees celebrated the milestone as a train loaded with low-sulfur coal left for Kansas City Power and Light Co.'s electricity generating station. Black Thunder achieved this milestone in just 14 years of operation.⁴¹

Trends for Crawler Tractors

The new crawler tractors of the 1990's have advanced hand-in-hand with technology. Today's mining tractors are almost twice the size of tractors that were manufactured 20 years ago. While horsepower and weight have now seemingly leveled off, more emphasis is being placed in specialized areas.

The most significant advances in crawler technology have been with undercarriages. There really have not been any major design modifications, but rather a fine-tuning of what is already present. Quality improvements, such as seal and metallurgy, extend the wear life of today's undercarriages. The ultimate goal of any manufacturer is to produce a maintenance-free undercarriage.

Also high in importance are tracks and grousers. There have been several significant changes to grouser and track design in the past 5 years. More alloys have been incorporated into grousers to increase life, while maintaining a balance between materials that are too soft or too

brittle. Constant minor improvements to track seals usually go unnoticed, but such changes add to track life.

The higher operating weight and horsepower of today's machines allow one machine to perform the work previously accomplished with two. Horsepower and weight, however, are not the answer to larger demands. Instead, the machine needs to be balanced to take full advantage of high horsepower and weight.

Fine-tuning has found its way into rippers as well. Although there have been no significant changes in ripper mechanics, current model rippers travel through materials at a much faster rate. The larger dozers can rip unblasted limestone, which was unheard of in the past. An assortment of accessories, such as specialized ripper tips, assist the operator. Impact rippers, a ripper that uses an internal percussive force, allows modern dozers to rip what was once thought to be unrippable. Also, closer attention has been placed on operator visibility. Adding to safety, an improved line-of-sight ensures operator confidence.

Manufacturers expect electronics to be the driving force of continued improvements. Onboard diagnostics will warn of out-of-tolerance conditions and will show what is causing the conditions. Operator errors can be discussed openly to avoid repetition. The diagnostics will also record and track preventive maintenance. Possible breakdowns can be charted and either avoided or planned for. Recorded data, such as maintenance history and fuel consumption, provide good information for maintenance and operator management.⁴²

Dragline Bucket Design

High technology has also entered the world of bucket design. Major dragline and bucket manufacturers have engineering teams devoted strictly to bucket design. With the advent of computer-aided design (CAD) and finite-element analysis (FEA), several innovations have been made in the design process.

Bucket research over the past several years has resulted in many new innovations. Most of the major changes revolve around the center of gravity. The geometry of buckets has been changed to make more use of the pulling force of the dragline rather than the bucket weight to achieve maximum tooth penetration. This change allowed the removal of weight while maintaining the key elements of structural integrity and wear protection. This weight savings directly translated into additional bucket capacity.

Through the use of new technological advances, dragline and bucket manufacturers have created durable buckets by dropping some of the weight after careful design analysis. The most common technique for increasing bucket size is to widen the lip. Such a move reduces the cutting force per inch of lip width, which is detrimental to performance. The bucket simply will not dig effectively in hard material, which further adds to drag-fill time.⁴³

New Equipment

Caterpillar introduced the world's largest mechanical drive truck in 1991. The Caterpillar 793 truck offers miners a new 217-ton hauling unit for large mine haulage capacity with mechanical drive efficiency. The 793 is designed to be shovel loaded in three to four passes for high productivity and lower cost per ton. The 793 uses a Cat 3516 turbocharged and aftercooled 16 cylinder diesel engine. An electronically controlled, six-speed powershift transmission gives a 33.3-miles-per-hour (mph) maximum travel speed. The dual-slope body with V-bottom helps center the load, reduces spillage, and maintains a low center of gravity. Weight distribution of the truck is 46.3% on the front axle and 53.7% on the rear axle. The loaded weight is 33.7% on the front axle and 66.3% on the rear axle. Overall length is 42.25 ft; width, 22.4 ft; and height, 21.1 ft. Gross vehicle weight is 355 tons.⁴⁴

After an investment of millions of dollars in more than 12 years of research and development, Komatsu has

introduced its D575A-2 dozer, the world's largest. Komatsu used a design approach that allows the D575A-2 to generate needed drawbar pull without a proportional increase in machine weight. The V-12 Komatsu engine and the vehicle's weight of 132 tons produce an impressive drawbar pull of 200 tons. A huge 70-cubic-yard (yd³) U-dozer blade or a 58.9-yd³ semi-U dozer blade accommodates a large quantity of material per cycle for increased productivity. This giant blade, a high-output engine, and Komatsu's Resilient Equalized Undercarriage (REU) allow the D575A-2 to push at least 50% more material per hour than the Komatsu D475A-2, the company's next largest dozer. The entire dozer blade is made of high tensile strength steel for increased durability. An optional dual-tilt blade system concentrates blade force where maximum penetration is needed.⁴⁵

After 8 years of design and testwork, Voest Alpine has developed the VASM, a surface miner intended for continuous extraction of materials in block operations. The cutting system of the VASM is quite different from other European-built surface miners, such as the Krupp and Wirtgen machines. It comprises a series of tooled cutter drums, which both rotate and oscillate, and a boom that positions the drums. It has four drums fitted with 48 rock picks. To adapt the cutting action to a wide range of rock types and to yield required products sizes, the rotational speed, frequency of oscillation, depth of cut, and rate of lowering can be controlled as appropriate. The VASM is crawler mounted and can operate at gradients of up to 20%, with crossfall of up to 5%. The machine is equipped with an onboard loading/conveying system that can deliver cut material to either trucks or conveyors. The cabin is positioned so that the operator has an excellent view of the working face. Full-function remote control and data transfer are also possible. Equipment is available that allows the operator to control the payload delivered at design level and to measure actual production in tons.⁴⁶

The Cat model 994 is the biggest machine Caterpillar has ever made. The Cat model 994 is also the largest mechanical-drive, front-end loader being manufactured today.⁴⁷ It approaches 60 ft in length, stands more than 21 ft in height with the bucket on the ground, and can load a Cat 789 truck (180 st) in six passes. In breakout force, it rivals the smaller hydraulic excavators (210,000 lb). The 994 wheel loader has a 70,000-lb bucket payload (about 35 st), which can be carried in bucket volumes from 18 to 26 yd³. A 40-yd³ bucket is available for coal, and a 16-yd³ spaded-edge bucket with teeth is available for denser materials, such as iron ore. The 994 was formally introduced at Cyprus Sierrita's surface copper mine south of Tucson, AZ, in late 1990.⁴⁸

O&K and Ziemens has introduced a state-of-the-art bucket wheel excavator (BWE). Bagger 292 is a BWE weighing approximately 13,500 tons, 738 ft in overall length, with a central tower structure 315 ft high. The main advantages offered by the 292 are more precise controls, a better working environment for the operator, and a better working protection of the machine's environment. Excavating accuracy is improved by three new systems. Laser guidance is used to ensure that the BWE stays on exactly the right plane. Gamma radiation sensors are used to track the coal/sandstone boundary so that no waste is mined. And the third system—already used on O&K hydraulic excavators—allows the details of a first, operator-controlled cut to be memorized for subsequent automatic replication. Also upgraded are the systems for condition monitoring of major mechanical and electrical functions, so that the operator gets early warning of any impending problems. In regard to the impact of the BWE on its surrounding when working, the main improvement has been the addition of water sprays for dust suppression.⁴⁹

Atlas Copco's Construction and Mining division launched a new tophammer drilling system that the company feels could bring about a revolution in blasthole drilling. Known as COPROD,

it is claimed that the system opens the way for more powerful rock drills to be used with retained, perfect hole straightness and an improved drill-string life expectancy. The result of more than 10 years of research and development, the COPROD concept is nevertheless simple. It utilizes threadless hydraulic rock drills. The new version is equipped with an anvil that transmits percussion and a tube chuck that transmits rotation. Maximum impact power output is 40 kW, with a corresponding frequency of 3,000 blows per minute. Atlas Copco claims that features of the system include a penetration rate twice that of DTH drilling, accuracy in drilling equal to tube or DTH drilling, superior drill string service life, and drills that are lighter in relation to the hole dimensions.⁵⁰

Diamond Bit Technology

Those involved in the diamond drilling industry for the past 15 to 20 years have doubtless marvelled at the advances that have occurred recently, as far as diamond bits are concerned. The past 10 years have seen bit life increase from performance measured in tens of feet up to hundreds of feet.

The technical advances made in synthetic or engineered diamonds, powder metallurgy, furnace equipment, etc., have all contributed to the progress of impregnated diamond bit technology. The manufacturing process involved in achieving the levels of performance now commonplace is becoming increasingly sophisticated, requiring substantial investment in new equipment. The powder metals utilized in current technology could certainly be described as "exotic" and require very advanced methods of handling, treatment, storage, and processing to take advantage of the benefits accruing from their use.

One notable advance has been the introduction of PCD products to the coal mining and oilfield industries. PCD compacts consist of synthetic diamond layers integrally sintered to tungsten carbide backing to form a hard abrasion-resistant cutting disk. These products drill with a shearing rather than a

crushing or grinding action. The 100% exposure of these cutters results in higher penetration rates than have been possible with conventional surface set products or the more recent impregnated bits. PCD drill bits have rapidly replaced the more conventional drill bits used in cable bolting, cross-measure drilling, methane drainage, and surface open-hole drilling.⁵¹

Blasting Primers

Spherical primers, a new shape in primers, are able to uniformly initiate a bulk explosive in a blasthole in all directions. The new spherical-shaped primer was developed after many years of research by ICI Australia Explosives Group in Deer Park, Victoria, Australia. It is expected to be particularly effective in surface coal mines where blasters need considerable forward movement, as in cast blasting when the bulk explosives must react as quickly and fully as possible, and in highwall conditions where it is necessary that the toe must move out effectively.

The spherical primers are also aimed at applications using large-diameter (9- to 18-in) holes, 100 to 150 ft deep, in which special blasting agents such as heavy Anfo, pumped explosives, and microspheres for extra sensitivity are employed.

Conical boosters, another variation on the shape of cylindrical cast boosters and primers, have proven to be highly effective in protecting the coal seam from damage during blasting. Developed and tested by Trojan Corp. during the past 4 years, the shape of the novel unit is actually frusto-conical—a part of a cone blending with a cylinder.⁵²

REMOTE MINING

Borehole Detection Systems

The German mining company Preussag AG Metall has developed an ore detection probe, the Preussag Slimhole Analyzer (PSA), for more accurate stopping. The PSA system has successfully been applied for 4 years at Preussag's lead and zinc mines near Bad Grund. The system is

designed for ordinary 1.58-in-diameter blastholes. Ore analyses from holes up to 70 ft long are displayed immediately at the drilling site. The PSA uses X-ray fluorescence. It measures moderate to high lead and zinc grades but can be modified for other ores. The PSA is specifically designed for rapid analysis. The procedure is almost fully automatic; the only manual operations are the positioning of the probe at the hole collar and pushing the start button on the control panel. This control panel also permits the interruption of the measuring procedure at any time, changing of program parameters, and checking the apparatus.

Because the measuring principle of the PSA is independent of the element being measured and the detection system is constructed modularly, adaptation of the system to other types of ore should be possible. This promises an extended field of application for the PSA system. Any deposit with exacting requirements for close-range reconnaissance is a prime candidate where the ability to define cutoff grades is of interest. A selective extraction of rich ore (such as the copper zones in massive sulfide deposits) combined with the avoidance of nonpay mineralization is possible with this system.⁵³

The Swedish company Abem AD has developed a system to investigate rock formations and obtain a direct and easily read picture of the rock around tunnels and boreholes. Rock absorbs radio waves, but there is a frequency range between 10 and 100 MHz that can be used to send out a pulse from a borehole and measure reflections in the surrounding rock. Abem makes use of this phenomenon in its Ramac system. The system was developed as a part of a large project of Svensk Karnbranslehantering AB (SKB) in Stripa, in the Vastmanland province. The project is a collaboration between the nuclear fuel authorities in Canada, Finland, Great Britain, Japan, Sweden, Switzerland, and the United States. To build safe storage locations for nuclear fuel, the designer needs a very clear picture of the rock

formation surrounding the proposed building site.

The equipment has even more applications. It can be used anywhere there is a borehole, as long as the rock does not absorb radar waves. The system provides excellent results in limestone, gneiss, and granite. It can also be used in places where limestone has become weak from disintegration and small cracks. A possible application is in connection with boring tunnels. Another is in mining to "look" in front of the work area and see where dangerous weak spots are located.⁵⁴

A new, gyro-based, all-attitude downhole surveying system, called the Smart⁵⁵ System, is being offered by Humphrey, Inc., and is applicable to vertical, horizontal, or a combination of vertical-horizontal holes. It is effectively a steering tool that includes supporting computer software and provides real-time viewing of all outputs both as raw voltages and computer angular displacements. The computerized system orchestrates the borehole surveying sequence, automatically initiating tie-on survey/realignment procedures as required to continually survey any deviation in the direction of the borehole. It is a three-part system that consists of a surface control unit, a gyroscope attitude-sensing borehole probe, and survey-coordinating computer software. Using gyroscopic attitude sensing, performance is unaffected by low level erratic magnetic fields and can be used in steel pipe.⁵⁶

Electromagnetic Imaging

Using electromagnetic (EM) fields and imaging techniques similar to those used in medicine, engineers at Sandia National Laboratories have devised new methods to aid in the difficult task of detecting unmapped mine entries. The electromagnetic technique has improved detection accuracy, which often is hampered by the presence of mineral deposits and by the variety of subterranean rock and sediment. By using lower frequency EM signals than have been used in other detection

methods, Sandia researchers have been able to reduce the incidence of false signals, which can be triggered by mineral deposits and other naturally occurring materials. Low frequencies—in this case, between 128 hertz and 9,216 hertz—are more effective because they can travel longer between distances underground.⁵⁷

Continuous Miner Automation

As technology advances, full automation of underground mining moves closer and closer toward reality. The U.S. Bureau of Mines, in an effort to develop technology for computer-assisted mining systems, is working on laser-guided navigation. The current research focus is the guidance of a continuous miner during room-and-pillar mining.

The system used Lasernet laser-scanning sensors that report the angular coordinates of retroreflective targets. The lasers, on a stationary reference structure, horizontally scan a beam of laser light across laser targets mounted at fixed locations on the continuous miner. A microcomputer system processes the laser data, determines position and heading, handles requests for data, and controls tram maneuvers.⁵⁸

Santa Cruz In Situ Leaching Project

The successful injection and recovery of saline and bromine solutions at the Santa Cruz In Situ Copper Mining Research Project outside Casa Grande, AZ, have lead the joint venturers and the U.S. Bureau of Mines to begin preparing for the permitting process for a pilot scale well-field and surface plant.

The copper mining research project is designed to determine the feasibility of mining a deeply buried copper deposit in situ, or in place, by injecting a dilute solution of sulfuric acid to dissolve the contained oxide copper minerals. The copper-laden solution then would be pumped to the surface where the copper would be recovered in a solvent extraction/electrowinning plant. The copper deposit is too deep and too low grade to be developed economically by

conventional underground or open pit mining methods.

The results of the field tests have been in the range predicted. There was no short circuiting of injected fluid, and indications are that a large volume of rock was contacted by the solution. Based on this projection, an adequate recovery of copper can be achieved.

The U.S. Bureau of Mines, which is studying the effects of drill core ore zone rocks on neutralization of dilute sulfuric acid, is generating the data to complete an environmental assessment as its portion of the project. Pending receipt of the necessary approvals, the pilot plant is expected to begin operation in 1993.⁵⁹

Coal Interface Detection Methods

The U.S. Bureau of Mines is developing the technology to create computer-assisted mining machines that will be capable of automatically tracking the boundaries of a coal seam and extracting only the desired material. If successful, this research should yield significant increases in mining productivity, worker safety, and quality of coal extract.

Several promising coal interface detection (CID) concepts currently being investigated by the Bureau include natural gamma radiation (NGR), machine vibration, and passive infrared (PIR).

The use of NGR sensors requires the strata adjacent to coal have higher levels of radiation than the coal seam to accurately measure the thickness of remaining coal. Commercially available NGR sensors have been used successfully as an autosteering technique on longwall miners and continuous miners in England since 1980.

The Bureau has obtained geological and mining data from more than 300 mines in the United States. Geological samples of the coal seam, roof, and floor have been collected from selected major seams and have been analyzed. NGR measurements made on these samples indicate that shaley materials typically have higher levels of NGR than coal. Results also indicate that in about 90% of the mines, the immediate roof and floor

strata consist of such shaley materials. This suggests that NGR sensors could be used in most coal seams in the United States.

Vibration sensing and analysis could be used as a possible CID method, provided that a definite contrast in mechanical strength exists between the coal and surrounding rock. The Bureau is investigating several vibrational CID approaches, including machine vibration, in-seam seismic, and acoustic methods.

A new CID concept that uses the PIR technique to measure temperature changes associated with the cutting of coal and adjacent strata is being investigated by the Bureau. Like the vibration method, a definite contrast in mechanical strength must exist between coal and rock for the PIR technique to work properly.

Advantages associated with this method are that the PIR responds instantaneously at the coal-rock interface and is minimally affected by dust or water sprays. Based on initial tests, results indicate that PIR can be applied successfully in mines having a hard immediate roof. It is expected that the end result of this research will lead to the development of a rugged, low-cost PIR-based CID sensing tool that can be routinely used by mine operators.⁶⁰

BENEFICIATION

Flotation

The installation of large-size column flotation cells is now being regularly considered by designers and operators of flotation circuits. The level of reliability of these larger units has reached a point where the equipment can be selected with confidence. Large-diameter column cells (more than 8 ft) have gained acceptance in mineral processing. The successful commissioning of 26.3- by 13.2-ft-square units at Minera Escondida's new copper concentrator in Chile, as well as 12-ft-diameter units at Ok Tedi Mining Ltd., in Papua, New Guinea, have demonstrated that large units can be successfully designed and operated. The larger units have been found to have a number of cost advantages over smaller units that merit

their consideration. The main advantage of large cells is their low capital costs per unit output and lower installation costs. Looking to the future, it will be interesting to see over the coming years what the upper limit for cell size will ultimately become.⁶¹

The performance of column flotation cells depends greatly on the froth phase. Yet, despite the importance of the froth phase, relatively few studies have been conducted that examined the impact of froth behavior on the performance of column flotation cells. This lack of information is surprising, considering that the froth phase is primarily responsible for the improved performance of columns over conventional flotation cells.

Laboratory flotation tests are being conducted by Virginia Polytechnic Institute to investigate the importance of the froth phase in column flotation cells. Experiments were designed to determine the ash and solids profiles within the froth column as a function of washwater. During high washwater rates, the data indicate most of the upgrading occurs at the froth-pulp interface. At lower washwater rates, additional upgrading occurs throughout the froth column in response to increased froth drainage. A simple volume balance around the froth zone of a column has been used to derive a relationship between column performance and froth behavior.⁶²

The Jameson cell is a new radical flotation device. The Jameson cell has only 25% of the height and mass specification of a column cell assigned the same plant duty. A throughput of 40 tons per hour per square foot of Jameson cell area is achievable. A total cell residence time of 2 minutes compares to the 45 minutes required by mechanical flotation cells. The cell is currently operational or under installation throughout Australia on coal, copper, lead, nickel, and zinc applications. Pilot testing is ongoing throughout the American, European, and African continents.⁶³

A fast air-injected hydrocyclone shallow tank (FAST) flotation system is being researched by the U.S. Bureau of Mines in Tuscaloosa, AL. Conventional flotation kinetics is a compromise

between two conflicting requirements—the need for an agitated zone for rapid bubble-particle collision and a quiescent zone for bubble-pulp separation. The Bureau has designed a flotation system in which bubble-particle collision and bubble separation are carried out in two unit operations. A bubble slurry and an ore slurry are mixed at a high rate in a modified air-injected hydrocyclone for rapid bubble-particle collision. The mixture is then fed into a unit specially designed for rapid separation of the bubbles from the pulp. The FAST system recovered copper ore much more quickly and as effectively during testing as a conventional flotation system.⁶⁴

The U.S. Bureau of Mines, under its Minerals and Materials Science Program, is investigating the feasibility of partitioning complex, difficult-to-process minerals into simple phases using sulfidation reactions. Such partitioning could improve the selective extraction of mineral constituents of value. Complex sulfide minerals such as chalcopyrite (CuFeS_2) and pentlandite [$(\text{Fe,Ni})_9\text{S}_8$] have been partitioned into the simple copper and iron sulfides (CuS plus FeS_2) and iron and nickel sulfides (FeS_2 plus NiS_2), respectively. Consequently, it may be possible to concentrate the simple, metal-rich phases by comminution and physical separation techniques, thus minimizing the troublesome emission of S-bearing gases presently associated with conventional roasting-smelting operations. The research revealed that the Cu contained in CuFeS_2 would convert to CuS in a matter of minutes as a result of processing the CuFeS_2 concentrate at 400°C in the presence of sulfur. More recently, experimentation has shown that similar processing of an ilmenite (FeTiO_3) concentrate results in partitioning of the Fe from the mineral complex to FeS , leaving an independent titanium oxide (TiO_2) phase. By applying conventional physical separation methods such as magnetic and/or flotation to these newly formed, independent phases, it may be possible to attain an upgraded TiO_2 product without total dissolution of the ilmenite, thus minimizing the environmental impact associated with

conventional processing. The research also indicated that simultaneous grinding during sulfidation could greatly increase the rate of reaction by continuously exposing new surfaces to the reacting species. The basic data developed by this research offer potential for innovative process modification to more efficiently separate high- and low-value constituents earlier in mineral processing operations.

A new flotation probe offers for the first time, reliable monitoring of froth and/or pulp levels in flotation cells. The Froth-Man probe was developed by the Atomic Energy Corp. of South Africa and is presently under test at Palabora Mining Co. Accurate measurement of both air/froth and froth/pulp interfaces leads to improved automatic control of flotation banks. The Froth-Man probe immediately determines whether or not froth or pulp is overflowing the lip and whether pulp level or frother addition needs adjusting.⁶⁵

The U.S. Bureau of Mines is investigating the potential of using color measurements as a potential technique for on-line monitoring of flotation froth properties in industrial circuits. Color measurements were made for pure minerals, mineral mixtures, and flotation froths loaded with different mixtures. An industrially available system consisting of a fiber-optic-based illuminator and detector was used to measure color. The device was able to detect differences in composition of mineral particle beds and mineralized froths. The color signal changed linearly as the ratios of chalcopyrite-to-pyrite and chalcopyrite-to-molybdenite mixtures were varied. Color measurements were also made on-line on a commercial copper-molybdenite rougher and cleaner circuits, and the measurements were found to be proportional to the copper-to-molybdenite ratio. Froth color monitors, when technology is developed to the commercial state, are nonnuclear and may provide instantaneous on-line information about froth composition. Color sensors have the potential to be multiplexed via fiber-optic cables such that one instrument may be able to monitor a number of flotation cells.

The U.S. Bureau of Mines has investigated a new method for increasing the selectivity in flotation by creating and regulating reagent concentration gradients within flotation columns at steady-state operation. Gradients were generated and traced in a water-only system with the use of fluorescent dyes under a variety of operating parameters. From this investigation, it was found that gradients could be generated in the froth cleaning zone and that they could be changed through manipulation of both physical and chemical operating parameters. The application of reagent gradient control to mineral systems could improve both flotation grade and recovery in commercial flotation operations without the use of additional flotation circuitry.

Coal Processing Methods and Equipment

A novel cleaning process for ultrafine coal has been developed at Virginia Tech that is capable of producing superclean products. This process, selective hydrophobic coagulation (SHC), uses pH modifier, the only chemical requirement for the process. Compared to other selective aggregation processes using hydrocarbons and flocculants, this process relies on the hydrophobicity of the coal surfaces to induce the selective coagulation of coal particulates in aqueous solution. The associated mineral matter is dispersed by simple pH control. As a result, the process is more economical and environmentally acceptable than other processes for treating micronized coal.⁶⁶

Pittsburgh Energy Technology Center (PETC) and the Electric Power Research Institute (EPRI) are experimenting with an advance fine-coal cleaning technique, spherical agglomeration. Bechtel National Inc. has demonstrated this process using Arcanum Corp. technology by constructing a 1/3-ton-per-hour unit at an EPRI test facility.

Although spherical agglomeration has been used commercially on fines, it has not become widely accepted in the coal industry due to the high cost of the petroleum bonding liquid and the odor

imparted to coal by the oil. The Arcanum/Bechtel process eliminates these impediments through the use of heptane, a recoverable hydrocarbon, to initiate the agglomeration process. Although it is inflammable, heptane has been demonstrated to be safe. The tests showed that spherical agglomeration can reduce pyritic sulfur from 70% to 90% and ash from 77% to 94%. Relatively dry (20% moisture), easily handled 3/8-in pellets can be produced from a pulverized coal slurry.⁶⁷

The use of dry magnetic separation has the potential to efficiently separate ash and pyritic sulfur from coal. Although the idea is about 20 years old, magnetic separation has not been applied to the commercial cleaning of coal for two principal reasons. First, there has been a lack of technical information on the magnetic makeup of American coals. Second, it has not been economically feasible to scale up conventional electromagnetic technology for applications in the coal processing industry. Recent developments in the areas of coal characterization and high field magnet design have made favorable changes in both of these crucial areas. A continuously operating, laboratory-scale magnetic separator has been developed by EXPORTech Co. Inc. Called the Para-Trap, the results obtained from operation indicate the laboratory separator can be scaled to commercial application. Dry magnetic separation has been proven effective in separating pyrites, ash, and sulfur-bearing minerals in sizes generally greater than 44 microns (μ) in a laboratory setting. Successful separations were carried out in all size ranges down to 325 mesh.⁶⁸

Mineral Processing Methods and Equipment

Technological advances continue in the application of superconducting magnetic separators in the treatment of minerals. A general trend in 1991 is the unceasing increase in the attainable magnetic field in various designs of magnetic separators with magnetic circuits based on permanent magnets, electromagnetic

conventional winding, as well as superconducting coils. Two manufacturers have developed separators that use this technology.

Master Magnets Ltd., Birmingham, AL, introduced its Series 1000 roll magnetic separators that can develop magnetic intensities exceeding 2 tons. Rolls 34.9 in long (feed width), with increased roll diameters, can reportedly treat higher tonnages of mineral. The separators are offered in one-, two-, four-, and six-roll versions. The multiroll separators enable retreatment of products on the lower rolls. Throughputs of up to 14 tons per hour of silica sand are reported. The roll speed is controlled by infinitely variable speed motor.

A separator developed by Cryogenic Consultants Ltd. London, is suitable for small producers and for production of special and high-quality materials. The Cryofilter High Gradient Magnetic Separator is designed for kaolin purification. Its throughput is up to 15 tons per hour, and the attainable induction of the magnetic field is up to 5 tons.⁶⁹

Outokumpu of Finland has for some years recognized the importance of efficient grinding control in mineral processing and the benefits in this area resulting from continuous particle size measurement. Elimination of overgrinding and undergrinding gives substantial cost benefits. Outokumpu has recently introduced its PSI-200 particle-size indicator that employs a simple yet innovative direct measurement technique that has been tested successfully on a variety of base metal, iron ore, and industrial mineral applications. Typical accuracies of 1% to 2% are achieved, reliability is reportedly excellent, and operating costs low. The screen-size range measurable is 28 to 500 mesh.⁷⁰

A recent development in the field of concentrate dewatering, the Outomec capillary-action filter, provides relatively low moisture contents at low operating costs. Capillary-action technology was originally developed in Finland for the papermaking industry. It soon became clear during the development process, however, that it was more suitable for

liquid-solid filtration in the mineral processing industry. The key to Outomec's capillary-action technology is a series of disks made out of a patented microporous sintered-alumina material, the inertness of which makes the disks suitable for the filtration of most water-based slurries. Each disk is constructed from a number of sectoral plates consisting of a permeable core to collect filtrate during dewatering.⁷¹

The EMDEE Microflot test is the only method that can determine the floatability spectrum of an ore by a simple direct experiment. Only a few inches of drill core provide enough material for 50 to 100 tests to determine the floatability of an ore. The method is fast, novel, accurate, and requires very small samples, 0.1 to 20 grams per test. The EMDEE package includes the Microflot agitator, a control unit, carrier for the centrifuge tube, and a software package.⁷²

On-Line Monitoring

One of the more recent developments changing the face of coal preparation has been the advent of on-line monitoring systems. These systems use gamma ray radiation to measure the various constituents of coal. On-line analyzers rapidly determine the ash content of coal both upstream and downstream from preparation plants, whether the coal is moving on conveyor belts or in a slurry. Some units provide elemental analysis of the other constituents, including moisture and sulfur. Such data are further analyzed to provide key information such as calorific values, pounds of SO₂ per million British thermal unit (Btu), total ash, and even ash fusion.

From such parameters, computer software uses the feedback of data to control plant processes, sorting and blending. Such controls and measurements are designed to reduce variations in the quality of coal, thereby minimizing penalties for out-of-spec coal and maximizing acceptable coal shipments.⁷³

A speedy and accurate on-line performance monitoring system, conceived by researchers at the

University of Kentucky's Institute of Mining and Minerals Research in Lexington, KY, can fine-tune gravity-based coal preparation operations to achieve the best quality product. The system, which uses fabricated tracer particles and metal detectors, is said to be a more scientific approach than the typical plant control methods that range from intuitive in-plant spot judgments to methods involving such devices as density gauges, floats, and on-the-spot float-sink tests.

The tracer system relies on magnetism during the washing process to trace and record the distribution of tagged synthetic particles of known size and specific gravity between the product and refuse output streams of coal or mineral.⁷⁴

Many mineral quality and processing specifications can be visually determined. The U.S. Bureau of Mines has developed an on-line computer vision-based system that is capable of the determining size distribution of flowing materials and is also capable of measuring particle shapes, brightness, and contrast. The system is nonobtrusive and is capable of measuring and controlling process parameters through a standard RS-485 serial port.

This computer vision system has been installed on the discharge belt of an agglomeration drum as part of a cooperative research project with the LTV Steel Co. and the Minnesota Department of Natural Resources. A visually based moisture content model has been developed using ball size and brightness as the independent parameters. Data have indicated the potential for controlling ball moisture content to within 0.1%. Accurate control of moisture content along with consistent ball size will result in better quality pellets with reduced operating costs.

Other applications include size and shape measurements of mine-run material and measurement during comminution processes. This system measured blast-size distribution with good correlation. It has also been used to measure the size distribution of feed to an autogenous mill.

Peroxide-Assisted Gold Leaching

The latest step in the chemical optimization of cyanidation is the use of hydrogen peroxide as a liquid oxidant. The peroxide-assisted leach (PAL) system allows the use of this strong oxidant in cyanidation while avoiding a reaction between H_2O_2 and cyanide. The availability of H_2O_2 in cyanidation significantly accelerates the extraction kinetics compared to standard technology that uses compressed air or oxygen as an oxidant. The optimized extraction kinetics leads to increased gold recoveries and reduced leach times. Furthermore, the use of a strong oxidant in cyanidation minimizes cyanide consumption by reducing the leach time, prevents cyanide losses by volatilization of HCN, and passivates cyanide-consuming sulfide minerals.

The main field of PAL application is the processing of sulfide ores, which are strongly oxygen and cyanide consuming. In contrast to standard aeration technology, the PAL process works very efficiently and economically on this ore type. The PAL process was first introduced to the mining industry about 3 years ago, and seven mines are currently using this technology. As oxide ore bodies are mined out and more sulfide gold ores must be mined, it is likely that PAL will become increasingly used in cyanidation.⁷⁵

Solvent Extraction and Electrowinning

Solvent extraction and electrowinning (SX-EW) in the worldwide copper industry continues to grow. Approximately 11% of the world copper supply is now produced by SX-EW methods, and new SX-EW plants commissioned in the past 3 years contribute 39% of all SX-EW production. As environmental laws become more stringent worldwide, particularly in the area of smelter emissions from conventional processing facilities, the trend toward primary copper production from SX-EW facilities is expected to definitely continue.

A few of the advantages of SX-EW technology over conventional mill smelter-refinery processing are the following:

- Low-cost copper cathode production (30 to 60 cents/lb).
- Environmental acceptability.
- Reduced capital costs compared with conventional facilities.
- The final product is high-quality, readily marketable cathode copper.⁷⁶

Warner Process

A new route from ore or concentrates to zinc metal could revolutionize the zinc industry. The net mine value of concentrates shipped to a distant smelter is typically 50% of the gross zinc value. The Warner Process should provide substantially higher returns by enabling zinc metal to be produced at the mine.

Other important advantages are that the process tolerates a higher percentage of gangue than permitted in zinc concentrates for shipment, and iron sulfide, because it is a heat source, is not a limitation. This means upstream flotation circuits can be operated for maximum recovery with little penalty on concentrate grade. Overall recovery from ore should therefore be higher.

The Warner Process has been under development by the University of Birmingham for the past 10 years, supported by the Mineral Industry Research Organization and the European Community, and is now ready to be taken through the final stages of engineering development.⁷⁷

HEALTH AND SAFETY

Safety Statistics

The number of coal mining deaths and injuries and the rates of fatalities and injuries per total hours worked in the United States dropped during the first 9 months of 1991 as compared to the same period of 1990, according to the Mine Safety and Health Administration (MSHA).

The rate of fatal injuries in coal mining was 0.04 injuries per 200,000 employee work-hours during the first 9 months of 1991, compared with 0.05 for the same period in 1990. Through September 1991, 45 miners were killed on the job, compared with 53 during the same period of 1990 and 55 for the first 9 months of 1989. Sixty-six coal miners died during all of 1990.

The rate of nonfatal coal mining injuries involving lost work time during the first 9 months of 1991 was 7.80 injuries per 200,000 employee-hours. This showed a decrease as compared with 7.82 in the same period of 1990 and 7.88 in the first 9 months of 1989. For the full year 1990, the nonfatal lost work time rate was 7.88. The rate for all types of injuries in coal mining was 10.02 per 200,000 work-hours in the first three quarters of 1991, compared with 10.08 for the same period in 1990.

The rate of fatal injuries in metal and nonmetal (noncoal) mining in the first half of 1991 was 0.02 per 200,000 employee-hours worked, compared with 0.03 for the same period of 1990, 0.03 for 1990 overall, and 0.02 for the same period on 1989. Twenty-two metal and nonmetal miners died in accidents through June 1991 compared with 29 for the same period in 1990, 56 for all of 1990, and 25 for the first half of 1989.

The rate of nonfatal lost-time injuries at metal and nonmetal mines was 3.98 for the first half of 1991, compared with 4.18 for the same period of 1990, 4.10 for all of last year, and 4.40 for the first half of 1989. The rate for all types of metal and nonmetal mining injuries for the first half of this year was 6.60 compared with 6.93 for the same period of 1990, 6.83 for all of last year, and 7.76 for the first half of 1989.⁷⁸

MSHA Regulations

MSHA plans to formulate new regulations to cover the hazards of work in confined spaces on mining property. Since 1980, about 78 fatal mining accidents have been related in some way to the hazards of work in confined spaces. While existing safety and health

standards cover some confined-space hazards, there is a need for a comprehensive regulation specifically targeting these types of dangers. MSHA has asked for input on the applicability of the concepts proposed by OSHA to the mining industry.⁷⁹

MSHA has revised Federal regulations for the handling of explosives and blasting in underground coal mines. The new rule changes the criteria for workers to be "qualified" to use explosives. The regulations deal with the hazard of stray electrical current, triggering detonators, and multiple-face blasts. Under the new rule, a miner must have had 1 year of experience with explosives before being designated as qualified—the experience could be gained in either mining or construction work.⁸⁰

MSHA announced civil fines totaling almost \$1 million against 14 mining companies and contractors in 9 States and Puerto Rico for negligent violations of safety and health regulations that led to deaths of 16 miners in fatal accidents. The civil penalties for 82 violations in 13 accidents that occurred between November 1990 and March 1991 included 8 \$50,000 fines—the highest dollar amount ever assessed by MSHA per violation. Another 26 violations were assessed penalties of \$10,000 to \$35,000. On November 5, 1990, Congress increased MSHA's maximum civil penalty amount per violation from \$10,000 to \$50,000. This group of penalties is the first to exceed the previous \$10,000 limit. Fines assessed in all of the accidents totaled \$976,020.⁸¹

Dust Control

One promising concept to reduce dust exposure to longwall miners is to maintain two splits of air along the entire length of the face. A curtain can create an intake split in the miners' walkway and a return (dusty) split over the face conveyor. The concept was earlier evaluated by the U.S. Bureau of Mines in trials using brattice. The brattice proved almost 100% effective in keeping the coal dust away from the miners, but severe visibility problems for the shearer

operators plagued its applicability underground. The Bureau has now come up with a way to maintain the air splits while eliminating the visibility handicap. The solution uses see-through polyester-mesh hung under roof shields where the lights are held.

Laboratory testing of the technique was conducted at the Bureau's Lake Lynn facility. A 500-ft test section of an entry was split with a mesh curtain containing 1/16-in and 1/8-in mesh openings at air velocities ranging between 200 to 800 ft/min. The 1/16-in mesh averaged better than a 60% clean split of air for the entire face over the whole air velocity range, while the 1/8-in mesh averaged almost a 50% clean split of air. Several vendors supply flame-retardant polyester material that meets MSHA standards.⁸²

Most of the dust from a longwall mining system is generated by the cutting action of the shearer drums. Numerous drum designs have been proposed to reduce dust generation, and one of the most promising is the so-called ventilating drum developed by the U.S. Bureau of Mines, working with Foster-Miller, Inc. The drum has 9 to 12 dust-capture tubes built into the shell of the shearer drum and arranged concentrically around the drum's center hub. High-pressure water is released from a spray ring manifold on the face side of the drum. The sprays act as a fan blowing toward the gob by entraining air and moving it from the face to the gob. The sprays also act as scrubbers, removing 90% to 95% of the respirable dust from the air drawn through the tubes. Because the tubes are open-ended and have no moving parts, it was thought that they would not be readily blocked by large debris. When tried under production conditions, however, the tubes did tend to block. Although this was not deemed an insurmountable problem, the Bureau came up with an alternative concept. Researchers took a conventional drum containing 26 low-pressure bit sprays on the shearer's bit blocks, angled the sprays 30° toward the face, installed new spray nozzles, and boosted the water spray pressure to about 1,000 psi. This resulted in an equivalent dust reduction

obtainable with the ventilating drum but without any of the associated maintenance problems.⁸³

Controlling quartz concentrations requires a different approach for respirable dust control. For instance, the wetting characteristics of quartz can be modified so that the capture efficiency is increased. The foam spray system is one such technique. Advantages of foam over conventional water sprays include the fact that a foam bubble has a larger surface area, which ensures better dust particulate capture. Also, foaming agents have better wettability characteristics than water.

A study was conducted in an operating mine to evaluate the effect of a compressed-air, foam-spray system mounted on a continuous miner. A foaming block containing two flat fan sprays was designed by the U.S. Bureau of Mines. It was welded to the back of the pan and directed so that the spray covered the pan and the gathering arms. Results of the study show that foam under-boom sprays appear to have a significant effect on quartz levels. Reduction in airborne intake dust concentrations was observed in 8 out of 11 cut comparisons. In the miner operator cab, however, the foam did not appear to reduce dust levels.⁸⁴

A shearer cutting drum that extracts up to 80% of respirable airborne dust in coal-cutting operations on longwall faces is felt to have substantial worldwide sales potential in areas where the longwall system of mining is used. More than 100 of the drums are currently in use in United Kingdom mines, helping to eliminate the health problems associated with airborne dust and also reducing the hazard of methane at the point of coal cutting. British Coal (BC), which developed the device, plans eventually to install this cutting device on all machines with which it is compatible.

The extraction drum was designed and developed over an extended period by BC's research and technical staff based on Bretby near Burton-on-Trent, England. The average life of a drum in regular use is 12 months, and it is estimated that there is a worldwide market for up to

1,000 drums per year. Development and field trials of the dust extraction unit have spanned a number of years. The unit uses high-pressure watersprays that direct air through a system of dust capture tubes fitted within the central hub of a standard cutting drum. Clean air is introduced to the cutting zone, diluting any methane gas that may be present and preventing the risk of frictional ignitions. Previous attempts to disperse methane at the face concentrated on improved ventilation, but this had the side effect of increasing dust dispersion. It is this dual hazard control aspect of the drum that makes it so significant to the coal mining industry.

A Mini-Scrubber Float Dust Filtration System to control float and respirable dust in underground mining, surface mining, and processing applications has been introduced by the Mining and Safety Supply Div. of the National Mine Service (NMS).

Engineered in a compact 2,000-ft³/min scrubber/fan package, the miniscrubber has cleaning efficiencies of 95% for respirable dust and 99% for float dust, reports NMS. According to the manufacturer, 1 gallon of water per minute at 60 psi is required to operate the system, compared with 5 to 10 gallons per minute or more with venturi and water-powered dust collectors. Dust-laden air drawn into the stainless steel unit mixes with water to form a slurry that is removed from the air by a demister. The slurry collects in a sump and drains onto the conveyor belt or is piped away to a drain.⁸⁶

Underground Fire Alarm

Recent research by the U.S. Bureau of Mines has demonstrated that encoded ultra-low-frequency (ULF) electromagnetic signaling can be used for an underground mine fire alarm. The system combines the transmission and reception of ULF EM fields through mine rock to send a fire-warning signal to underground miners. A magnetic field, generated about the transmitting loop antenna, transmits the signal. The field emanates from the transmitting antenna in a spherical manner.

What makes the system unique is the mobility of the receiving unit, which utilizes a ferric core antenna (5.9 in long) for signal reception. It has exceptional flux-gathering capabilities and can capture even the weakest electromagnetic signals. Also, the receiver is battery powered. It can be powered off of a cap-lamp battery or off of a vehicle, making the system completely portable and easy to carry. The prototype of the system has been tested at several mines. The signal transmission distance achieved during these tests was greater than 5,400 ft through overburden.⁸⁷

Lightning Warning System

Lightning has always been regarded as a serious threat to surface mine blasting operations. Recently, several detection techniques have been developed that permit a mine to more accurately determine when lightning is nearby.

Amax is applying a relatively inexpensive lightning tracking system, which is being linked to all of the company's midwestern surface mines. The tracking system is not only expected to help a mine prevent casualties from an unexpected lightning strike, but also to avoid having its blasting operations suspended unnecessarily. The system employs a satellite dish on a roof near a computer system. The different Amax mines are computer-linked. It was not until recently that access to a cost-effective and accurate timing source was made possible by technological breakthroughs and microprocessor design. The system selected by Amax is a time-of-arrival (TOA) system called lightning position and tracking system (LPATS).⁸⁸

Emergency Mine Vehicle

Several new technologies and some new inventions were introduced at the Ninth International Conference on Coal Research (ICCR), which was held recently in Washington, DC. Among the new inventions was the Numbat, presented by CSIRO, Div. of Geomechanics, located in Queensland, Australia.

Numbat, an emergency mine safety vehicle, is a single-hulled eight-wheeled, remotely controlled survey vehicle. The vehicle provides detailed information on underground conditions to the surface following a mine emergency such as a fire or explosion. It would operate in support of rescue, decreasing the chance of exposure to any unknown, and possibly dangerous, situations. The Numbat is one of only two postemergency coal mining survey vehicles known to be under development worldwide. The other is being produced by the Coal Mining Research Center-Japan, but details are unreported.⁸⁹

Rescue Through Drill Hole

Twenty-six coal miners trapped by a roof fall were rescued in Swaziland through a hole drilled from surface. It was the first of its kind in southern Africa, and one of very few in the world. Moreover, it is believed to be the largest number of men ever rescued through a drilled hole.

The Emaswati Coal Mine near Mpaka in the eastern Lowveld currently produces about 180,000 tons per year. About 350 workers are employed at the shallow (215-ft-deep) underground coal mine. At 10:00 a.m. on the morning of June 8, a 660-ft-long roof fall trapped a 26-employee crew inside the mine. An area 600 by 330 by 215 ft deep had collapsed to the surface. Drilling started at 3:15 a.m. and finally holed through at 11:45 a.m., a rate of about 30 feet per hour. Twenty-eight hours after being trapped, the workers were rescued. The drill has been used only once and, according to the South African Chamber of Mines, there were no problems. The equipment proved itself in the emergency.⁸⁹

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TABLE 1
MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES IN THE UNITED STATES,
BY TYPE

(Million short tons)

Type and year	Surface ¹			Underground			All mines ¹		
	Crude ore	Waste	Total	Crude ore	Waste	Total ¹	Crude ore	Waste	Total
Metals:									
1987	489	825	1,310	43	6	49	532	831	1,360
1988	637	951	1,590	31	6	37	668	957	1,620
1989	799	1,110	1,910	50	5	55	849	1,120	1,970
1990	779	1,340	2,120	59	4	63	838	1,350	2,190
1991	813	1,450	2,260	79	2	81	892	1,450	2,340
Industrial minerals:									
1987 ²	1,430	452	1,880	77	1	78	1,510	453	1,960
1988 ²	1,210	366	1,580	34	(³)	34	1,250	366	1,610
1989 ²	1,550	774	2,330	63	2	65	1,620	776	2,390
1990 ²	1,250	315	1,560	40	1	41	1,290	315	1,600
1991 ²	1,330	145	1,480	68	(³)	68	1,400	145	1,550
Total, metals and industrial minerals:¹									
1987	1,920	1,280	3,200	120	7	126	2,040	1,280	3,320
1988	1,990	1,320	3,310	65	6	72	2,050	1,320	3,380
1989	2,350	1,890	4,240	113	8	120	2,470	1,890	4,360
1990	2,030	1,660	3,680	99	5	104	2,120	1,660	3,790
1991	2,150	1,590	3,740	147	3	150	2,290	1,590	3,890

¹All data are rounded to three significant digits. Data may not add to totals shown because of independent rounding.

²Includes industrial sand and gravel. Construction sand and gravel data were not available for 1987, 1989, and 1991 because of biennial canvassing.

³Crushed and broken and dimension stone data were not available for 1988 and 1990 because of biennial canvassing.

⁴Less than 1/2 unit.

TABLE 2
MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES¹ IN THE UNITED STATES IN 1991, BY
COMMODITY AND STATE²

(Thousand short tons)

Commodity	Surface			Underground			Total material handled ³		
	Crude ore	Waste	Total	Crude ore	Waste	Total	Crude ore	Waste	Total
METALS									
Copper	328,000	W	328,000	46,100	30	46,100	374,000	30	374,000
Gold:									
Lode	245,000	799,000	1,040,000	5,620	1,180	6,800	250,000	800,000	1,050,000
Placer	10,800	14,200	24,900	—	—	—	10,800	14,200	24,900
Iron ore	210,000	W	210,000	W	—	W	210,000	W	210,000
Lead	—	W	W	7,670	W	7,670	7,670	W	7,670
Silver	W	(⁴)	W	3,620	262	3,890	3,620	262	3,890
Titanium	13,000	W	13,000	—	—	—	13,000	W	13,000
Zinc	W	W	W	5,590	W	5,990	5,590	W	5,990
Other ⁵	6,160	634,000	640,000	10,500	815	11,300	16,600	634,000	651,000
Total, metals	813,000	1,450,000	2,260,000	79,100	2,290	81,400	892,000	1,450,000	2,340,000

See footnotes at end of table.

TABLE 2—Continued
**MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES¹ IN THE UNITED STATES IN 1991, BY
 COMMODITY AND STATE²**

(Thousand short tons)

Commodity	Surface			Underground			Total material handled ³		
	Crude ore	Waste	Total	Crude ore	Waste	Total	Crude ore	Waste	Total
INDUSTRIAL MINERALS									
Barite	444	W	444	—	—	—	444	—	444
Boron minerals	1,400	—	1,400	—	—	—	1,400	—	1,400
Clays	44,300	37,700	82,000	74	1	75	44,400	37,700	82,100
Diatomite	2,100	W	2,100	—	—	—	2,100	W	2,100
Feldspar	951	—	951	—	—	—	951	—	951
Gypsum	13,700	8,190	21,900	1,940	—	1,940	15,600	8,190	23,800
Iron oxide pigments (crude)	26	—	26	—	—	—	26	—	26
Mica (scrap)	336	W	336	—	—	—	336	W	336
Perlite	835	W	835	W	—	W	835	W	835
Phosphate rock	167,000	—	167,000	W	—	W	167,000	—	167,000
Potash	—	—	—	2,150	—	2,150	2,150	—	2,150
Pumice ⁶	534	367	901	—	—	—	534	367	901
Salt	4,320	—	4,320	12,700	W	12,700	17,000	W	17,000
Sand and gravel	26,300	—	26,300	—	—	—	26,300	—	26,300
Soda ash	—	—	—	8,970	—	8,970	8,970	—	8,970
Stone:									
Crushed and broken	1,070,000	87,100	1,150,000	41,800	293	42,100	1,110,000	87,400	1,200,000
Dimension	2,480	1,270	3,780	7	—	7	2,500	1,270	3,760
Talc, soapstone, and pyrophyllite	1,220	W	1,220	W	W	W	1,220	W	1,220
Vermiculite	185	—	185	—	—	—	185	—	185
Other ⁷	2,290	10,500	12,800	407	19	426	2,700	10,600	13,300
Total, industrial minerals	1,330,000	145,000	1,480,000	68,100	313	68,400	1,400,000	145,000	1,550,000
Grand total	2,150,000	1,590,000	3,740,000	147,000	2,600	150,000	2,290,000	1,590,000	3,890,000
STATE									
Alabama	33,900	5,400	39,300	—	—	—	33,900	5,400	39,300
Alaska	7,990	W	7,990	W	W	W	7,990	W	7,990
Arizona	220,000	W	220,000	W	W	W	220,000	W	220,000
Arkansas	26,700	5,460	32,200	—	—	—	26,700	5,460	32,200
California	86,600	59,100	146,000	223	38	261	86,900	59,100	146,000
Colorado	12,500	5,970	18,500	W	106	106	12,500	6,070	18,600
Connecticut	6,420	584	7,000	—	—	—	6,420	584	7,000
Florida	219,000	W	219,000	—	—	—	219,000	W	219,000
Georgia	52,800	W	52,800	W	W	W	52,800	W	52,800
Hawaii	11,100	906	12,000	—	—	—	11,100	906	12,000
Idaho	14,800	6,880	21,700	529	262	792	15,400	7,140	22,500
Illinois	72,800	6,360	79,100	1,190	W	1,190	74,000	6,360	80,300
Indiana	38,900	4,000	42,900	W	W	W	38,900	4,000	42,900
Iowa	29,900	4,530	34,500	3,830	27	3,860	33,800	4,560	38,300
Kansas	17,800	1,540	19,300	2,580	6	2,590	20,400	1,540	21,900
Kentucky	33,500	3,440	36,900	13,700	96	13,800	47,200	3,540	50,700
Louisiana	5,480	704	6,190	5,440	—	5,440	10,900	704	11,600
Maine	1,750	174	1,920	—	—	—	1,750	174	1,920
Maryland	21,000	1,890	22,900	W	W	W	21,000	1,890	22,900
Massachusetts	7,340	687	8,030	—	—	—	7,340	687	8,030

See footnotes at end of table.

TABLE 2—Continued
**MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES¹ IN THE UNITED STATES IN 1991, BY
 COMMODITY AND STATE²**

(Thousand short tons)

Commodity	Surface			Underground			Total material handled ³		
	Crude ore	Waste	Total	Crude ore	Waste	Total	Crude ore	Waste	Total
STATE—Continued									
Michigan	82,500	W	82,500	W	W	W	82,500	W	82,500
Minnesota	175,000	W	175,000	—	—	—	175,000	W	175,000
Mississippi	3,150	1,360	4,510	—	—	—	3,150	1,360	4,510
Missouri	47,300	W	47,300	10,300	384	10,700	57,700	384	58,000
Montana	46,100	W	46,100	4,420	W	4,420	50,500	W	50,500
Nebraska	2,260	279	2,540	2,830	20	2,850	5,090	299	5,390
Nevada	176,000	640,000	817,000	395	W	395	177,000	640,000	817,000
New Hampshire	1,530	162	1,690	—	—	—	1,530	162	1,690
New Jersey	19,000	1,530	20,500	—	—	—	19,000	1,530	20,500
New Mexico	W	W	W	4,650	(⁴)	4,650	4,650	(⁴)	4,650
New York	36,500	3,680	40,200	W	W	W	36,500	3,680	40,200
North Carolina	64,800	W	64,800	—	—	—	64,800	W	64,800
Ohio	53,700	5,990	59,700	W	W	W	53,700	5,990	59,700
Oklahoma	32,500	W	32,500	W	W	W	32,500	W	32,500
Oregon	21,800	W	21,800	27	W	27	21,800	W	21,800
Pennsylvania	70,800	6,430	77,200	2,800	20	2,820	73,600	6,450	80,100
South Carolina	28,100	W	28,100	—	—	—	28,100	W	28,100
South Dakota	12,700	7,090	19,800	2,530	576	3,100	15,200	7,670	22,900
Tennessee	42,200	4,550	46,700	W	W	W	42,200	4,550	46,700
Texas	74,000	W	74,000	456	(⁴)	457	74,400	(⁴)	74,400
Utah	56,200	W	56,200	116	31	147	56,300	31	56,400
Vermont	3,300	469	3,770	W	—	W	3,300	469	3,770
Virginia	50,300	4,670	55,000	W	W	W	50,300	4,670	55,000
Washington	14,000	1,330	15,300	1,280	W	1,280	15,200	1,330	16,600
West Virginia	9,200	829	10,000	1,680	12	1,690	10,900	841	11,700
Wisconsin	26,500	2,100	28,600	—	—	—	26,500	2,100	28,600
Wyoming	6,380	W	6,380	8,970	—	8,970	15,300	W	15,300
Undistributed ⁵	69,900	804,000	874,000	79,100	1,020	80,200	149,000	805,000	954,000
Grand total	2,150,000	1,590,000	3,740,000	147,000	2,600	150,000	2,290,000	1,590,000	3,890,000

W Withheld to avoid disclosing company proprietary data; included with "Other" or "Undistributed."

¹Excludes materials from wells, ponds, or pumping operations.

²All data are rounded to three significant digits. Data may not add to totals shown because of independent rounding.

³Includes material from exploration and development activities.

⁴Less than 1/2 unit.

⁵Includes bauxite, beryllium, magnesium metal, manganese, molybdenum, platinum-group metals, rare-earth concentrates, tungsten, and metal items indicated by symbol W.

⁶Excludes volcanic cinder and scoria.

⁷Includes apatite, asbestos, fluorspar, greensand marl, kyanite, lithium minerals, magnesite, magnesium-brines, olivine, wollastonite, and industrial mineral items indicated by symbol W.

⁸Includes North Dakota, Rhode Island, and State items indicated by symbol W.

TABLE 3
**MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES¹ IN THE UNITED STATES IN 1990, BY
 COMMODITY AND STATE²**

(Thousand short tons)

Commodity or State	Surface			Underground			All mines ³		
	Crude ore	Waste	Total	Crude ore	Waste	Total	Crude ore	Waste	Total
METALS									
Bauxite	531	—	531	—	—	—	531	—	531
Copper	315,000	W	315,000	22,000	49	22,000	337,000	49	337,000
Gold:									
Lode	256,000	711,000	967,000	3,940	1,290	5,230	260,000	713,000	972,000
Placer	8,220	4,090	12,300	6	W	6	8,230	4,090	12,300
Iron ore	182,000	W	182,000	W	W	W	182,000	W	182,000
Lead	—	—	—	8,630	W	8,630	8,630	W	8,630
Silver	2,490	W	2,490	3,780	W	3,780	6,270	W	6,270
Titanium	11,500	W	11,500	—	—	—	11,500	W	11,500
Zinc	W	W	W	6,600	W	6,600	6,600	W	6,600
Other ⁴	2,510	628,000	631,000	14,200	2,720	16,900	16,700	631,000	647,000
Total, metals	779,000	1,340,000	2,120,000	59,200	4,060	63,200	838,000	1,350,000	2,190,000
INDUSTRIAL MINERALS									
Barite	244	W	244	—	—	—	244	W	244
Clays	46,300	40,200	86,500	269	4	272	46,500	40,200	86,800
Diatomite	3,130	W	3,130	—	—	—	3,130	W	3,130
Feldspar	2,030	W	2,030	—	—	—	2,030	W	2,030
Gypsum	13,300	15,000	28,300	3,080	W	3,080	16,400	15,000	31,400
Iron oxide pigments (crude)	28	—	28	—	—	—	28	—	28
Mica (scrap)	261	W	261	—	—	—	261	W	261
Perlite	766	W	766	W	—	W	766	W	766
Phosphate rock	167,000	W	167,000	W	—	W	167,000	W	167,000
Potash	—	—	—	11,800	—	11,800	11,800	—	11,800
Pumice ⁵	732	12	743	—	—	—	732	12	743
Salt	2,590	—	2,590	16,000	W	16,000	18,600	W	18,600
Sand and gravel	933,000	—	933,000	—	—	—	933,000	—	933,000
Soda ash	—	—	—	8,210	W	8,210	8,210	W	8,210
Talc, soapstone, and pyrophyllite	1,420	1,330	2,760	W	W	W	1,420	1,330	2,760
Vermiculite	235	—	235	—	—	—	235	—	235
Other ⁶	76,200	258,000	334,000	431	693	1,130	76,600	259,000	336,000
Total, industrial minerals	1,250,000	315,000	1,560,000	39,900	697	40,600	1,290,000	315,000	1,600,000
Grand total	2,030,000	1,660,000	3,680,000	99,000	4,760	104,000	2,120,000	1,660,000	3,790,000
STATE									
Alabama	17,300	2,100	19,400	W	W	W	17,300	2,100	19,400
Alaska	22,500	14,400	36,900	W	W	W	22,500	14,400	36,900
Arizona	213,000	284,000	498,000	W	W	W	213,000	284,000	498,000
Arkansas	11,900	W	11,900	—	—	—	11,900	W	11,900
California	166,000	45,200	211,000	218	102	320	166,000	45,300	211,000
Colorado	27,000	3,430	30,400	8,930	219	9,150	35,900	3,650	40,000
Connecticut	8,850	W	8,850	—	—	—	8,850	W	8,850
Delaware	2,180	—	2,180	—	—	—	2,180	—	2,180
Florida	176,000	W	176,000	—	—	—	176,000	W	176,000
Georgia	15,900	W	15,900	—	—	—	15,900	W	15,900

See footnotes at end of table.

TABLE 3—Continued
**MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES¹ IN THE UNITED STATES IN 1990, BY
 COMMODITY AND STATE²**

(Thousand short tons)

Commodity or State	Surface			Underground			All mines ³		
	Crude ore	Waste	Total	Crude ore	Waste	Total	Crude ore	Waste	Total
STATE—Continued									
Idaho	19,100	W	19,100	1,360	W	1,360	20,400	W	20,400
Illinois	37,900	843	38,800	W	W	W	37,900	843	38,800
Indiana	25,200	1,010	26,200	W	W	W	25,200	1,010	26,200
Iowa	16,900	W	16,900	W	—	W	16,900	W	16,900
Kansas	12,900	600	13,500	W	—	W	12,900	600	13,500
Kentucky	10,100	892	11,000	W	—	W	10,100	892	11,000
Louisiana	15,800	W	15,800	5,720	—	5,720	21,500	W	21,500
Maryland	18,700	324	19,000	—	—	—	18,700	324	19,000
Michigan	74,400	40,300	115,000	W	W	W	74,400	40,300	115,000
Minnesota	200,000	W	200,000	—	—	—	200,000	W	200,000
Mississippi	14,500	1,100	15,600	—	—	—	14,500	1,100	15,600
Missouri	11,600	1,460	13,000	9,540	W	9,540	21,100	1,460	22,600
Montana	46,400	W	46,400	3,840	W	3,840	50,300	W	50,300
Nebraska	11,700	218	11,900	—	—	—	11,700	218	11,900
Nevada	209,000	578,000	787,000	663	W	663	210,000	578,000	788,000
New Jersey	15,200	W	15,200	—	—	—	15,200	W	15,200
New Mexico	W	W	W	15,500	W	15,500	15,500	W	15,500
New York	30,800	W	30,800	5,750	W	5,750	36,500	W	36,500
North Carolina	29,200	W	29,200	—	—	—	29,200	W	29,200
North Dakota	7,700	48	7,750	—	—	—	7,700	48	7,750
Ohio	49,700	2,760	52,400	W	W	W	49,700	2,760	52,400
Oklahoma	13,400	W	13,400	—	—	—	13,400	W	13,400
Oregon	17,100	W	17,100	—	W	W	17,100	W	17,100
Pennsylvania	22,500	829	23,300	—	—	—	22,500	829	23,300
Rhode Island	2,040	—	2,040	—	—	—	2,040	—	2,040
South Carolina	20,300	W	20,300	—	—	—	20,300	W	20,300
South Dakota	16,700	20,200	37,000	1,760	559	2,310	18,500	20,800	39,300
Tennessee	10,700	1,210	11,900	W	W	W	10,700	1,210	11,900
Texas	51,900	W	51,900	W	W	W	51,900	W	51,900
Utah	64,100	W	64,100	163	25	188	64,200	25	64,200
Vermont	4,290	W	4,290	—	—	—	4,290	W	4,290
Virginia	15,000	W	15,000	W	W	W	15,000	W	15,000
Washington	40,800	152	41,000	1,150	W	1,150	42,000	152	42,100
West Virginia	3,860	157	4,010	—	—	—	3,860	157	4,010
Wisconsin	30,300	—	30,300	—	—	—	30,300	—	30,300
Wyoming	7,600	W	7,600	8,210	W	8,210	15,800	W	15,800
Undistributed ⁷	187,000	659,000	846,000	36,200	3,860	40,100	223,000	663,000	886,000
Grand total ²	2,030,000	1,660,000	3,680,000	99,000	4,760	104,000	2,120,000	1,660,000	3,790,000

W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Excludes materials from wells, ponds, or pumping operations.

²All data are rounded to three significant digits. Data may not add to totals shown because of independent rounding.

³Includes material from exploration and development activities.

⁴Includes beryllium, magnesium metal, manganese, mercury, molybdenum, platinum-group metals, tungsten, uranium, and metal items indicated by symbol W.

⁵Excludes volcanic cinder and scoria.

⁶Includes apatite, asbestos, boron minerals, fluor spar, greensand marl, kyanite, magnesite, olivine, salt, wollastonite, and industrial mineral items indicated by symbol W.

⁷Includes Hawaii, Maine, Massachusetts, New Hampshire, and State items indicated by symbol W.

TABLE 4
**VALUE OF PRINCIPAL MINERAL PRODUCTS AND BYPRODUCTS OF SURFACE AND UNDERGROUND ORES
 MINED IN THE UNITED STATES IN 1991**

(Value per short ton)

Ore	Surface			Underground			All mines		
	Principal mineral product	By-product	Total ¹	Principal mineral product	By-product	Total ¹	Principal mineral product	By-product	Total ¹
METALS									
Copper	\$9.95	\$1.19	\$11.13	\$15.05	\$1.31	\$16.36	\$10.42	\$1.20	\$11.62
Gold:									
Lode	10.65	.86	11.52	45.15	3.80	48.96	11.40	.93	12.33
Placer	3.13	.25	3.39	—	—	—	3.13	.25	3.39
Iron ore	7.94	W	7.94	W	W	W	7.94	W	7.94
Lead	—	—	—	29.88	32.42	62.30	29.88	32.42	62.30
Silver	W	W	W	14.41	18.66	33.06	14.41	18.66	33.06
Titanium	3.25	W	3.25	—	—	—	3.25	W	3.25
Zinc	W	W	W	30.49	.45	30.94	30.49	.45	30.94
Average, metals ²	9.54	.85	10.38	19.77	5.70	25.47	10.28	1.20	11.48
INDUSTRIAL MINERALS									
Barite	24.88	—	24.88	—	—	—	24.88	—	24.88
Boron minerals	297.74	W	297.74	—	—	—	297.74	W	297.74
Clays	32.17	.33	32.50	W	W	W	32.17	.33	32.50
Diatomite	71.85	—	71.85	—	—	—	71.85	—	71.85
Feldspar	24.51	8.00	32.51	—	—	—	24.51	8.00	32.51
Gypsum	6.09	W	6.09	5.53	—	5.53	6.02	W	6.02
Iron oxide pigments (crude)	76.00	—	76.00	—	—	—	76.00	—	76.00
Mica (scrap)	14.28	W	14.28	—	—	—	14.28	W	14.28
Perlite	22.59	—	22.59	W	—	W	22.59	—	22.59
Phosphate rock	5.97	—	5.97	W	—	W	5.97	—	5.97
Potash	—	—	—	72.87	—	72.87	72.87	—	72.87
Pumice ³	18.08	—	18.08	—	—	—	18.08	—	18.08
Salt	40.19	13.49	53.68	16.28	W	16.28	22.65	W	22.65
Sand and gravel	14.52	.26	14.78	—	—	—	14.52	.26	14.78
Soda ash	—	—	—	82.74	—	82.74	82.74	—	82.74
Stone:									
Crushed and broken	4.62	.02	4.64	7.07	—	7.07	4.71	.02	4.73
Dimension	72.25	.10	72.35	W	—	W	72.25	.10	72.35
Talc, soapstone, and pyrophyllite	27.25	1.10	28.35	W	—	W	27.25	1.10	28.35
Vermiculite	72.45	—	72.45	—	—	—	72.45	—	72.45
Average, industrial minerals ²	6.75	.11	6.86	21.15	.81	21.96	7.44	.14	7.59
Average, industrial minerals (excluding sand and gravel) ²	6.59	.11	6.70	21.15	.81	21.96	7.31	.14	7.45
Average, metals and industrial minerals ²	7.83	.39	8.22	20.47	3.23	23.69	8.56	.56	9.12
Average, metals and industrial minerals (excluding sand and gravel) ²	7.74	.39	8.14	20.47	3.23	23.69	8.49	.56	9.05

W Withheld to avoid disclosing company proprietary data.

¹Data may not add to totals shown because of independent rounding.

²Includes unpublished data.

³Excludes volcanic cinder and scoria.

TABLE 5
VALUE OF PRINCIPAL MINERAL PRODUCTS AND BYPRODUCTS OF SURFACE AND UNDERGROUND ORES
MINED IN THE UNITED STATES IN 1990

(Value per short ton)

Ore	Surface			Underground			All mines		
	Principal mineral product	By-product	Total ¹	Principal mineral product	By-product	Total ¹	Principal mineral product	By-product	Total ¹
METALS									
Bauxite	\$13.52	W	\$13.52	—	—	—	\$13.52	W	\$13.52
Copper	11.67	\$1.11	12.78	\$20.94	\$1.21	\$22.14	12.27	\$1.12	13.38
Gold:									
Lode	13.45	1.28	14.74	33.35	7.63	40.98	13.83	1.40	15.23
Placer	3.90	(²)	3.90	18.91	—	18.91	3.90	(²)	3.91
Iron ore	7.52	1.10	8.61	W	W	W	7.52	1.10	8.61
Lead	—	—	—	36.08	34.73	70.80	36.08	34.73	70.80
Silver	9.80	4.68	14.48	20.65	16.59	37.23	16.43	11.95	28.38
Titanium	4.45	5.44	9.88	—	—	—	4.45	5.44	9.88
Zinc	W	W	W	45.91	2.06	47.97	45.91	2.06	47.97
Average, metals ³	11.45	1.29	12.74	25.58	7.53	33.11	12.48	1.74	14.21
INDUSTRIAL MINERALS									
Barite	22.09	—	22.09	—	—	—	22.09	—	22.09
Clays	31.97	.39	32.36	W	W	W	31.97	.39	32.36
Diatomite	46.20	—	46.20	—	—	—	46.20	—	46.20
Feldspar	5.16	9.00	14.16	—	—	—	5.16	9.00	14.16
Gypsum	6.00	—	6.00	6.36	—	6.36	6.07	—	6.07
Iron oxide pigments (crude)	96.87	—	96.87	—	—	—	96.87	—	96.87
Mica (scrap)	19.28	—	19.28	—	—	—	19.28	—	19.28
Perlite	22.46	—	22.46	W	—	W	22.46	—	22.46
Phosphate rock	21.04	—	21.04	W	—	W	21.04	—	21.04
Potash	—	—	—	21.14	—	21.14	21.14	—	21.14
Pumice ⁴	18.62	—	18.62	—	—	—	18.62	—	18.62
Salt	66.93	W	66.93	12.82	W	12.82	21.22	W	21.22
Sand and gravel	3.85	—	3.85	—	—	—	3.85	—	3.85
Soda ash	—	—	—	41.62	W	41.62	41.62	W	41.62
Talc, soapstone, and pyrophyllite	23.63	—	23.63	W	—	W	23.63	W	23.63
Vermiculite	225.19	—	225.19	—	—	—	225.19	—	225.19
Average, industrial minerals ³	6.40	.08	6.48	21.87	9.55	31.42	6.95	.42	7.37
Average, industrial minerals (excluding sand and gravel) ³	25.63	.66	26.29	21.87	9.55	31.42	24.73	2.79	27.52
Average, metals and industrial minerals ³	8.53	.59	9.12	24.12	8.33	32.44	9.34	.99	10.32
Average, metals and industrial minerals (excluding sand and gravel) ³	13.41	1.20	14.61	24.12	8.33	32.44	14.48	1.91	16.40

W Withheld to avoid disclosing company proprietary data.

¹Data may not add to totals shown because of independent rounding.

²Less than 1/2 unit.

³Includes unpublished data.

⁴Excludes volcanic cinder and scoria.

TABLE 6
**CRUDE ORE AND TOTAL MATERIAL HANDLED AT SURFACE AND
 UNDERGROUND MINES IN THE UNITED STATES IN 1991, BY
 COMMODITY AND STATE**

(Percent)

Commodity	Crude ore		Total material	
	Surface	Underground	Surface	Underground
METALS				
Copper	87.7	12.3	94.6	5.4
Gold:				
Lode	97.8	2.2	99.4	.6
Placer	100.0	—	100.0	—
Iron ore	¹ 100.0	W	¹ 100.0	W
Lead	—	100.0	W	² 100.0
Silver	W	² 100.0	W	² 100.0
Titanium	100.0	—	100.0	—
Zinc	W	² 100.0	W	² 100.0
Average, metals ³	91.1	8.9	96.5	3.5
INDUSTRIAL MINERALS				
Barite	100.0	—	100.0	—
Boron minerals	100.0	—	100.0	—
Clays	¹ 100.0	W	¹ 100.0	W
Diatomite	100.0	—	100.0	—
Feldspar	100.0	—	100.0	—
Gypsum	87.6	12.4	91.9	8.1
Iron oxide pigments (crude)	100.0	—	100.0	—
Mica (scrap)	100.0	—	100.0	—
Perlite	¹ 100.0	W	¹ 100.0	W
Phosphate rock	¹ 100.0	W	¹ 100.0	W
Potash	—	100.0	—	100.0
Pumice ⁴	100.0	—	100.0	—
Salt	25.4	74.6	25.4	74.6
Sand and gravel	100.0	—	100.0	—
Soda ash	—	100.0	—	100.0
Stone:				
Crushed and broken	96.2	3.8	96.5	3.5
Dimension	¹ 100.0	W	¹ 100.0	W
Talc, soapstone, and pyrophyllite	¹ 100.0	W	¹ 100.0	W
Vermiculite	100.0	—	100.0	—
Average, industrial minerals ³	95.1	4.9	95.6	4.4
Average, metals and industrial minerals ³	93.6	6.4	96.2	3.8
STATE				
Alabama	100.0	—	100.0	—
Alaska	¹ 100.0	W	¹ 100.0	W
Arizona	¹ 100.0	W	¹ 100.0	W
Arkansas	100.0	—	100.0	—
California	99.7	.3	99.8	.2
Colorado	61.9	38.1	70.3	29.7
Connecticut	100.0	—	100.0	—
Florida	100.0	—	100.0	—
Georgia	¹ 100.0	W	¹ 100.0	W
Hawaii	100.0	—	100.0	—

See footnotes at end of table.

TABLE 6—Continued
**CRUDE ORE AND TOTAL MATERIAL HANDLED AT SURFACE AND
 UNDERGROUND MINES IN THE UNITED STATES IN 1991, BY
 COMMODITY AND STATE**

(Percent)

Commodity	Crude ore		Total material	
	Surface	Underground	Surface	Underground
STATE—Continued				
Idaho	96.6	3.4	96.5	3.5
Illinois	98.4	1.6	98.5	1.5
Indiana	¹ 100.0	W	¹ 100.0	W
Iowa	88.6	11.4	89.9	10.1
Kansas	87.3	12.7	88.2	11.8
Kentucky	70.9	29.1	72.7	27.3
Louisiana	¹ 100.0	W	¹ 100.0	W
Maine	100.0	—	100.0	—
Maryland	¹ 100.0	W	¹ 100.0	W
Massachusetts	100.0	—	100.0	—
Michigan	93.1	6.9	95.7	4.3
Minnesota	100.0	—	100.0	—
Mississippi	100.0	—	100.0	—
Missouri	82.1	17.9	83.0	17.0
Montana	91.2	8.8	96.1	3.9
Nebraska	44.4	55.6	47.1	52.9
Nevada	¹ 100.0	W	¹ 100.0	W
New Hampshire	100.0	—	100.0	—
New Jersey	100.0	—	100.0	—
New Mexico	92.5	7.5	97.7	2.3
New York	¹ 100.0	W	¹ 100.0	W
North Carolina	100.0	—	100.0	—
Ohio	¹ 100.0	W	¹ 100.0	W
Oklahoma	¹ 100.0	W	¹ 100.0	W
Oregon	99.9	.1	99.8	.2
Pennsylvania	96.2	3.8	96.5	3.5
South Carolina	100.0	—	100.0	—
South Dakota	83.4	16.6	86.4	13.6
Tennessee	82.5	17.5	83.7	16.3
Texas	99.4	.6	99.5	.5
Utah	99.8	.2	99.9	.1
Vermont	¹ 100.0	W	¹ 100.0	W
Virginia	¹ 100.0	W	¹ 100.0	W
Washington	91.6	8.4	91.0	9.0
West Virginia	84.5	15.5	85.6	14.4
Wisconsin	100.0	—	100.0	—
Wyoming	41.6	58.4	68.4	31.6
Average, States ³	93.6	6.4	96.2	3.8

W Withheld to avoid disclosing company proprietary data; included with "Surface" or "Underground."

¹Includes underground to avoid disclosing company proprietary data.

²Includes surface to avoid disclosing company proprietary data.

³Includes unpublished data.

⁴Includes abrasive stone and millstones.

TABLE 7
CRUDE ORE AND TOTAL MATERIAL HANDLED AT SURFACE AND
UNDERGROUND MINES IN THE UNITED STATES IN 1990, BY
COMMODITY AND STATE

(Percent)

Commodity or State	Crude ore		Total material	
	Surface	Underground	Surface	Underground
METALS				
Bauxite	100.0	—	100.0	—
Copper	93.5	6.5	97.2	2.8
Gold:				
Lode	98.5	1.5	99.5	.5
Placer	99.9	.1	99.9	.1
Iron ore	¹ 100.0	W	¹ 100.0	W
Lead	—	100.0	—	100.0
Silver	39.7	60.3	84.7	15.3
Titanium	100.0	—	100.0	—
Zinc	W	² 100.0	W	² 100.0
Average, metals ³	92.9	7.1	97.1	2.9
INDUSTRIAL MINERALS				
Barite	100.0	—	100.0	—
Clays	99.4	.6	99.7	.3
Diatomite	100.0	—	100.0	—
Feldspar	100.0	—	100.0	—
Gypsum	81.2	18.8	90.2	9.8
Iron oxide pigments (crude)	100.0	—	100.0	—
Mica (scrap)	100.0	—	100.0	—
Perlite	99.0	1.0	99.0	1.0
Phosphate rock	99.9	.1	99.9	.1
Potash	—	100.0	—	100.0
Pumice ⁴	100.0	—	100.0	—
Salt	13.9	86.1	13.6	86.4
Sand and gravel	100.0	—	100.0	—
Soda ash	—	100.0	—	100.0
Talc, soapstone, and pyrophyllite	98.7	1.3	98.8	1.2
Vermiculite	100.0	—	100.0	—
Average, industrial minerals ³	96.9	3.1	97.5	2.5
Average, metals and industrial minerals ³	95.3	4.7	97.3	2.7
STATE				
Alabama	¹ 100.0	W	¹ 100.0	W
Alaska	¹ 100.0	W	¹ 100.0	W
Arizona	¹ 100.0	W	¹ 100.0	W
Arkansas	100.0	—	100.0	—
California	99.9	.1	99.8	.2
Colorado	75.2	24.8	76.9	23.1
Connecticut	100.0	—	100.0	—
Florida	100.0	—	100.0	—
Georgia	100.0	—	100.0	—
Hawaii	¹ 100.0	W	¹ 100.0	W
Idaho	83.4	16.6	94.4	5.6
Illinois	W	² 100.0	W	² 100.0

See footnotes at end of table.

TABLE 7—Continued
**CRUDE ORE AND TOTAL MATERIAL HANDLED AT SURFACE AND
 UNDERGROUND MINES IN THE UNITED STATES IN 1990, BY
 COMMODITY AND STATE**

(Percent)

Commodity or State	Crude ore		Total material	
	Surface	Underground	Surface	Underground
STATE—Continued				
Indiana	W	² 100.0	W	² 100.0
Iowa	W	² 100.0	W	² 100.0
Kansas	W	² 100.0	W	² 100.0
Kentucky	W	² 100.0	W	² 100.0
Louisiana	73.4	26.6	74.3	25.7
Maine	¹ 100.0	W	¹ 100.0	W
Maryland	100.0	—	100.0	—
Massachusetts	¹ 100.0	W	¹ 100.0	W
Michigan	W	² 100.0	W	² 100.0
Minnesota	100.0	—	100.0	—
Mississippi	100.0	—	100.0	—
Missouri	54.8	45.2	54.3	45.7
Montana	92.4	7.6	96.3	3.7
Nebraska	100.0	—	100.0	—
Nevada	99.7	.3	99.8	.2
New Hampshire	¹ 100.0	W	¹ 100.0	W
New Jersey	100.0	—	100.0	—
New Mexico	¹ 100.0	W	¹ 100.0	W
New York	84.2	15.8	84.7	15.3
North Carolina	100.0	—	100.0	—
North Dakota	100.0	—	100.0	—
Ohio	¹ 100.0	W	¹ 100.0	W
Oklahoma	100.0	—	100.0	—
Oregon	100.0	—	99.7	.3
Pennsylvania	100.0	—	100.0	—
Rhode Island	100.0	—	100.0	—
South Carolina	100.0	—	100.0	—
South Dakota	90.5	9.5	94.1	5.9
Tennessee	¹ 100.0	W	¹ 100.0	W
Texas	¹ 100.0	W	¹ 100.0	W
Utah	99.7	.3	99.9	.1
Vermont	100.0	—	100.0	—
Virginia	97.5	2.5	97.7	2.3
Washington	97.3	2.7	97.1	2.9
West Virginia	100.0	—	100.0	—
Wisconsin	100.0	—	100.0	—
Wyoming	48.1	51.9	75.8	24.2
Average, States ³	95.3	4.7	97.3	2.7

W Withheld to avoid disclosing company proprietary data; included with "Surface" or "Underground."

¹Includes underground to avoid disclosing company proprietary data.

²Includes surface to avoid disclosing company proprietary data.

³Includes unpublished data.

⁴Includes abrasive stone and millstones.

⁵Excludes volcanic cinder and scoria.

TABLE 8
**NUMBER OF DOMESTIC METAL AND INDUSTRIAL MINERAL MINES¹ IN THE UNITED STATES IN 1991,
 BY COMMODITY AND STATE**

Commodity	Total number of mines	Less than 1,000 tons	1,000 to 10,000 tons	10,000 to 100,000 tons	100,000 to 1,000,000 tons	1,000,000 to 10,000,000 tons	More than 10,000,000 tons
METALS							
Copper	29	—	1	3	1	13	11
Gold:							
Lode	106	2	6	9	34	53	2
Placer	18	4	6	3	2	3	—
Iron ore	26	—	2	6	7	5	6
Lead	12	—	—	2	6	4	—
Silver	6	—	—	2	3	1	—
Titanium	4	—	1	—	2	—	1
Zinc	11	—	—	1	7	3	—
Others ²	24	10	2	4	4	4	—
Total, metals	236	16	18	30	66	86	20
INDUSTRIAL MINERALS							
Barite	4	—	1	1	2	—	—
Boron minerals	3	—	1	—	1	1	—
Clays	771	27	208	402	133	1	—
Diatomite	11	—	1	5	5	—	—
Feldspar	11	—	2	4	5	—	—
Gypsum	62	—	4	16	42	—	—
Iron oxide pigments (crude)	3	2	—	1	—	—	—
Mica (scrap)	12	—	7	4	1	—	—
Perlite	10	1	2	4	3	—	—
Phosphate rock	22	—	—	—	1	11	10
Potash	5	—	—	—	5	—	—
Pumice ³	20	2	7	10	1	—	—
Salt	27	—	—	4	17	6	—
Sand and gravel ⁴	143	3	10	62	66	2	—
Soda ash	5	—	—	—	—	5	—
Stone:							
Crushed and broken	4,367	366	812	1,265	1,692	232	—
Dimension	247	55	114	77	1	—	—
Talc, soapstone, pyrophyllite	23	1	3	14	5	—	—
Vermiculite	5	—	—	5	—	—	—
Others ⁵	16	1	2	6	6	1	—
Total, industrial minerals	5,767	458	1,174	1,880	1,986	259	10
Grand total	6,003	474	1,192	1,910	2,052	345	30
STATE							
Alabama	105	—	23	31	38	13	—
Alaska	32	1	6	14	8	3	—
Arizona	82	2	10	32	17	14	7
Arkansas	81	2	14	23	36	6	—
California	353	39	172	64	78	—	—
Colorado	81	3	23	36	13	6	—
Connecticut	26	1	1	11	11	2	—
Florida	138	—	—	39	68	21	10
Georgia	212	1	27	75	99	10	—

See footnotes at end of table.

TABLE 8—Continued
**NUMBER OF DOMESTIC METAL AND INDUSTRIAL MINERAL MINES¹ IN THE UNITED STATES IN 1991,
 BY COMMODITY AND STATE**

Commodity	Total number of mines	Less than 1,000 tons	1,000 to 10,000 tons	10,000 to 100,000 tons	100,000 to 1,000,000 tons	1,000,000 to 10,000,000 tons	More than 10,000,000 tons
STATE—Continued							
Hawaii	30	—	4	10	12	4	—
Idaho	71	—	15	29	20	7	—
Illinois	191	2	15	73	86	15	—
Indiana	114	3	5	28	70	8	—
Iowa	261	9	54	107	89	2	—
Kansas	152	7	32	59	54	—	—
Kentucky	107	—	8	25	67	7	—
Louisiana	20	—	1	8	5	6	—
Maine	14	1	1	5	7	—	—
Maryland	39	1	5	10	16	7	—
Massachusetts	35	3	3	10	18	1	—
Michigan	69	2	13	15	26	12	1
Minnesota	78	1	8	29	32	3	5
Mississippi	26	—	—	18	8	—	—
Missouri	237	5	29	85	106	12	—
Montana	41	4	3	14	12	7	1
Nebraska	18	2	2	8	4	2	—
Nevada	88	4	6	21	29	26	2
New Hampshire	14	—	4	5	5	—	—
New Jersey	39	—	5	11	16	7	—
New Mexico	81	13	15	34	16	1	2
New York	127	8	14	25	71	9	—
North Carolina	171	10	18	49	84	9	1
Ohio	169	4	18	43	92	12	—
Oklahoma	93	5	10	26	48	4	—
Oregon	533	148	144	189	52	—	—
Pennsylvania	229	10	16	54	138	11	—
South Carolina	80	—	9	29	35	7	—
South Dakota	31	—	5	10	10	6	—
Tennessee	164	—	18	32	107	7	—
Texas	286	27	42	98	100	19	—
Utah	68	9	19	24	10	5	1
Vermont	48	7	14	12	15	—	—
Virginia	129	7	5	33	70	14	—
Washington	444	61	254	92	36	1	—
West Virginia	72	1	29	20	20	2	—
Wisconsin	257	6	33	151	64	3	—
Wyoming	172	64	34	63	11	—	—
Undistributed ⁶	95	1	6	31	23	34	—
Total, States	6,003	474	1,192	1,910	2,052	345	30

¹Based on crude ore mined. Excludes wells, ponds, or pumping operations.

²Includes bauxite, beryllium, magnesium metal, manganese, molybdenum, platinum-group metals, rare-earth concentrates, tungsten, vanadium, and zirconium concentrates.

³Excludes volcanic cinder and scoria.

⁴Includes industrial sand and gravel. Construction sand and gravel data were not available for 1991 because of biennial canvassing.

⁵Includes apatite, asbestos, fluorspar, greensand marl, kyanite, lithium minerals, magnesite, magnesium-brine, olivine, and wollastonite.

⁶Includes North Dakota, Rhode Island, and undistributed data.

TABLE 9
NUMBER OF DOMESTIC METAL AND INDUSTRIAL MINERAL MINES¹ AND OUTPUT RANGES IN THE UNITED STATES IN 1990, BY COMMODITY AND STATE

Commodity or State	Total number of mines	Less than 1,000 tons	1,000 to 10,000 tons	10,000 to 100,000 tons	100,000 to 1,000,000 tons	1,000,000 to 10,000,000 tons	More than 10,000,000 tons
METALS							
Bauxite	3	—	—	2	1	—	—
Copper	26	4	1	1	1	7	12
Gold:							
Lode	142	5	9	17	55	53	3
Placer	25	5	7	3	7	3	—
Iron ore	23	—	1	6	5	6	5
Lead	14	—	1	1	8	4	—
Silver	10	1	2	—	5	2	—
Titanium	4	—	—	1	2	—	1
Zinc	12	1	—	—	8	3	—
Others ²	42	15	10	10	4	—	3
Total, metals	301	31	31	41	96	78	24
INDUSTRIAL MINERALS							
Barite	10	—	4	6	—	—	—
Clays	784	20	187	439	138	—	—
Diatomite	12	—	2	3	7	—	—
Feldspar	12	—	1	5	6	—	—
Gypsum	62	—	3	14	45	—	—
Iron oxide pigments (crude)	3	1	1	1	—	—	—
Mica (scrap)	16	1	10	4	1	—	—
Perlite	10	1	2	4	3	—	—
Phosphate rock	18	—	—	—	4	9	5
Potash	6	—	—	—	3	3	—
Pumice ³	11	—	2	6	3	—	—
Salt	24	—	—	3	14	7	—
Sand and gravel	5,739	110	822	2,651	2,034	121	1
Soda ash	4	—	—	—	—	4	—
Talc, soapstone, pyrophyllite	28	2	5	16	5	—	—
Vermiculite	6	—	1	5	—	—	—
Others ⁴	19	1	3	8	6	—	1
Total, industrial minerals	6,764	136	1,043	3,165	2,269	144	7
Grand total	7,065	167	1,074	3,206	2,365	222	31
STATE							
Arkansas	77	1	14	40	21	1	—
California	363	8	26	114	168	47	—
Colorado	269	12	50	126	76	5	—
Connecticut	73	1	9	28	35	—	—
Florida	66	—	3	16	32	10	5
Georgia	134	—	17	69	48	—	—
Idaho	96	3	10	41	37	5	—
Louisiana	92	—	8	39	42	3	—
Maryland	66	1	7	28	27	3	—
Minnesota	279	7	24	145	91	7	5

See footnotes at end of table.

TABLE 9—Continued
NUMBER OF DOMESTIC METAL AND INDUSTRIAL MINERAL MINES¹ AND OUTPUT RANGES IN THE UNITED STATES IN 1990, BY COMMODITY AND STATE

Commodity or State	Total number of mines	Less than 1,000 tons	1,000 to 10,000 tons	10,000 to 100,000 tons	100,000 to 1,000,000 tons	1,000,000 to 10,000,000 tons	More than 10,000,000 tons
STATE—Continued							
Mississippi	107	1	5	63	38	—	—
Missouri	132	2	32	60	32	6	—
Nebraska	171	3	23	118	27	—	—
Nevada	183	10	19	44	73	34	3
New Jersey	70	—	5	27	36	2	—
New Mexico	145	13	19	63	44	4	2
New York	427	17	132	176	100	2	—
North Carolina	188	2	36	104	44	1	1
Oklahoma	162	8	39	78	37	—	—
Pennsylvania	165	2	21	76	65	1	—
Rhode Island	12	—	2	4	6	—	—
South Carolina	94	2	13	39	37	3	—
Texas	282	—	28	129	119	6	—
Utah	137	7	23	58	45	3	1
Vermont	86	6	18	49	13	—	—
Washington	213	4	36	83	82	8	—
West Virginia	12	—	2	3	7	—	—
Wisconsin	244	6	29	127	81	1	—
Wyoming	160	3	43	91	19	4	—
Undistributed ⁵	2,560	48	381	1,168	883	66	14
Total, States	7,065	167	1,074	3,206	2,365	222	31

¹Excludes wells, ponds, or pumping operations.

²Includes beryllium, magnesium metal, manganese, mercury, molybdenum, platinum-group metals, and tungsten.

³Excludes volcanic cinder and scoria.

⁴Includes apatite, asbestos, boron minerals, fluorspar, greensand marl, kyanite, magnesite, olivine, and wollastonite.

⁵Includes Alabama, Alaska, Arizona, Delaware, Hawaii, Illinois, Indiana, Iowa, Kansas, Kentucky, Maine, Massachusetts, Michigan, Montana, New Hampshire, North Dakota, Ohio, Oregon, South Dakota, Tennessee, Virginia, and undistributed data.

TABLE 10
TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL¹ MINES IN THE UNITED STATES IN 1991, IN ORDER OF OUTPUT OF CRUDE ORE

Mine ²	State	Operator	Commodity	Mining method
METALS				
Carlin Mines Complex	Nevada	Newmont Gold Co.	Gold	Open pit.
Mintac	Minnesota	USX Corp.	Iron ore	Do.
San Manuel	Arizona	Magma Copper Co.	Copper	Open pit and stoping.
Morenci	do.	Phelps Dodge Corp.	do.	Open pit.
Bingham Canyon	Utah	Kennecott, Utah Copper Corp.	do.	Do.
Sierrita	Arizona	Cyprus Sierrita Corp.	do.	Do.
Tyrone	New Mexico	Phelps Dodge Corp. and Burro Chief Copper Co.	do.	Do.
Hibbing	Minnesota	Hibbing Taconite Co.	Iron ore	Do.
Bagdad	Arizona	Cyprus Bagdad Copper Co.	Copper	Do.
Inspiration	do.	Cyprus Miami Mining Corp.	do.	Do.
Empire	Michigan	Empire Iron Mining Partnership	Iron ore	Do.

See footnotes at end of table.

TABLE 10—Continued
**TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL¹ MINES IN THE UNITED STATES
 IN 1991, IN ORDER OF OUTPUT OF CRUDE ORE**

Mine ²	State	Operator	Commodity	Mining method
METALS—Continued				
Pinto Valley	Arizona	Pinto Valley Copper Corp.	Copper	Open pit.
Erie	Minnesota	LTV Steel Mining Co.	Iron ore	Do.
Continental	Montana	Montana Resources Inc.	Copper	Do.
Hurley	New Mexico	Phelps Dodge Corp.	do.	Do.
NSPC Project	Minnesota	National Steel Pellet Co.	Iron ore	Do.
Sleeper	Nevada	Amax Gold Inc.	Gold	Do.
Smokey Valley Common Operation	do.	Round Mountain Gold Corp.	do.	Do.
Ray	Arizona	ASARCO Incorporated	Copper	Do.
Zortman-Landusky	Montana	Pegasus Gold Inc.	Gold	Do.
Green Cove	Florida	Associated Minerals Corp.	Titanium	Dredging.
Wind Mountain	Nevada	Amax Gold Inc.	Gold	Open pit.
Thunderbird	Minnesota	Eveleth Mines	Iron ore	Do.
McCoy and Cove	Nevada	Echo Bay Mining Co.	Gold	Do.
Mission Complex	Arizona	ASARCO Incorporated	Copper	Do.
INDUSTRIAL MINERALS ³				
Florida mines (5)	Florida	International Minerals & Chemicals Corp.	Phosphate rock	Open pit.
Florida mines (2)	do.	Agrico Chemical Co.	do.	Do.
Do.	do.	Mobil Mining and Minerals Co. .	do.	Do.
Lee Creek	North Carolina	Texasgulf Chemical Co.	do.	Do.
Fort Meade	Florida	Cargill Fertilizer Inc.	do.	Do.
Hookers Prairie		W. R. Grace & Co.	do.	Do.
Calcite	Michigan	Michigan Minerals Associates	Stone	Open quarry.
Reed	Kentucky	Reed Crushed Stone Co.	do.	Do.
Wingate Creek	Florida	Nu-Gulf Industries Inc.	Phosphate rock	Dredging.
Stoneport	Michigan	Presque Isle Corp.	Stone	Open quarry.
Thornton	Illinois	General Dynamics Corp., Material Services Co.	do.	Do.
Marblehead	do.	do.	do.	Do.
McCook	do.	Vulcan Materials Co.	do.	Do.
Rockland	Florida	U.S. Agri-Chemicals Co.	Phosphate rock	Open pit.
St. Genevieve	Missouri	Tower Rock Stone Co.	Stone	Open quarry.
Georgetown	Texas	Texas Crushed Stone Co.	do.	Do.
Pensuco	Florida	Tarmac America Inc.	do.	Dredging.
Calcium	Maryland	Genstar Stone Products Co.	do.	Stoping.
White Rock	Florida	Vecelio & Grogan Inc.	do.	Open quarry.
Mount Hope	New Jersey	Mount Hope Rock Products Inc. .	do.	Do.
Granite Mountain	Arkansas	McGeorge Contracting Co., Inc.	do.	Do.
Clinton	New York	Lone Star Industries, New York Trap Rock Corp.	do.	Do.
Norcross	Georgia	Vulcan Materials Co.	do.	Do.
FEC Hialeah	Florida	Rinker Materials Corp.	do.	Do.
3 Rivers	Kentucky	Dravo Basic Materials Co., Inc.	do.	Do.

¹Excludes brines and materials from wells.

²Owing to commodity reporting differences, individual mine data may not be available.

³Includes industrial sand and gravel. Construction sand and gravel were not available for 1991 because of biennial canvassing.

TABLE 11
**TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL¹ MINES IN THE UNITED STATES
 IN 1990, IN ORDER OF OUTPUT OF CRUDE ORE**

Mine ²	State	Operator	Commodity	Mining method
METALS				
Tyrone	New Mexico	Phelps Dodge Corp. and Burro Chief Copper Co.	Copper	Open pit.
Carlin Mines Complex	Nevada	Newmont Gold Co.	Gold	Do.
Minntac	Minnesota	USX Corp.	Iron ore	Do.
Morenci	Arizona	Phelps Dodge Corp.	Copper	Do.
Bingham Canyon	Utah	Kennecott, Utah Copper Corp.	do.	Do.
Sierrita	Arizona	Cyprus Sierrita Corp.	do.	Do.
Hibbing	Minnesota	Hibbing Taconite Co.	Iron ore	Do.
Erie	do.	LTV Steel Mining Co.	do.	Do.
Bagdad	Arizona	Cyprus Bagdad Copper Co.	Copper	Do.
Inspiration	do.	Cyprus Miami Mining Corp.	do.	Do.
Pinto Valley	do.	Pinto Valley Copper Corp.	do.	Do.
Continental	Montana	Montana Resources Inc.	do.	Do.
NSPC Project	Minnesota	National Steel Pellet Co.	Iron ore	Do.
Hurley	New Mexico	Phelps Dodge Corp.	Copper	Do.
San Manuel	Arizona	Magma Copper Co.	do.	Stoping.
Smokey Valley Common Operation	Nevada	Round Mountain Gold Corp.	Gold	Open pit.
Buffalo Valley	do.	Horizon Gold Shares Inc.	do.	Do.
Thunderbird	Minnesota	Eveleth Mines	Iron ore	Do.
Ray	Arizona	ASARCO Incorporated	Copper	Do.
Sleeper	Nevada	Amex Gold Inc.	Gold	Do.
Zortman-Landusky	Montana	Pegasus Gold Inc.	do.	Do.
Goldstrike	Nevada	Barrick Goldstrike Mines Inc.	do.	Do.
Green Cove	Florida	Associated Minerals Corp.	Titanium	Dredging.
Mission Complex	Arizona	ASARCO Incorporated	Copper	Open pit.
McCoy and Cove	Nevada	Echo Bay Mining Co.	Gold	Do.
INDUSTRIAL MINERALS³				
Florida mines (5)	Florida	International Minerals & Chemicals Corp.	Phosphate rock	Open pit.
Florida mines (2)	do.	Agrico Chemical Co.	do.	Do.
Do.	do.	Mobil Mining and Minerals Co.	do.	Do.
Lee Creek	North Carolina	Texasgulf Chemical Co.	do.	Dredging.
Fort Meade	Florida	Cargill Fertilizer Inc.	do.	Open pit.
Hookers Prairie	do.	W. R. Grace & Co.	do.	Do.
Sun Valley	California	CalMat Co. of California	Sand and gravel	Dredging.
International	New Mexico	International Minerals & Chemicals Corp.	Potash	Stoping.
Steilacoom	Washington	Lone Star Northwest	Sand and gravel	Dredging.
Rockland	Florida	U.S. Agri-Chemicals Corp.	Phosphate rock	Open pit.
Radum	California	Beazer West Inc.	Sand and gravel	Dredging.
Dobson	Arizona	Salt River Sand and Rock	do.	Do.
Azusa	California	Southdown Inc.	do.	Do.
Milford	Michigan	E. C. Levy Co.	do.	Do.
Perkins	California	A. Teichert & Son Inc., Teichert Aggregates	do.	Do.
Irwindale	do.	Beazer West Inc.	do.	Do.
Durbin	do.	CalMat Co. of California	do.	Do.

See footnotes at end of table.

TABLE 11—Continued
**TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL¹ MINES IN THE UNITED STATES
 IN 1990, IN ORDER OF OUTPUT OF CRUDE ORE**

Mine ²	State	Operator	Commodity	Mining method
INDUSTRIAL MINERALS³—Continued				
Retsof	New York	Akzo Salt Inc.	Salt	Stoping.
Bonanza	Nevada	Beazer West Inc.	Sand and gravel	Dredging.
Lone Mountain	do.	Nevada Ready Mix Co.	do.	Do.
Irwindale	California	United Rock Products Corp.	do.	Do.
Redlands	do.	C. L. Pharris Sand and Gravel Inc.	do.	Do.
Iowa mines (18)	Iowa	Hallett Materials Co.	do.	Do.
Briggs	Texas	Fordyce Co.	do.	Do.
Corona	California	All American Asphalt Co.	do.	Do.

¹Excludes brines and materials from wells.

²Due to commodity reporting differences, individual mine data may not be available.

³Crushed and broken and dimension stone were not available for 1990 because of biennial canvassing.

TABLE 12
**TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL¹ MINES IN THE UNITED STATES
 IN 1991, IN ORDER OF OUTPUT OF TOTAL MATERIALS HANDLED**

Mine ²	State	Operator	Commodity	Mining method
METALS				
Morenci	Arizona	Phelps Dodge Corp.	Copper	Open pit.
Carlin Mines Complex	Nevada	Newmont Gold Co.	Gold	Do.
Goldstrike	do.	Barrick Goldstrike Mines Inc.	do.	Do.
Hurley	New Mexico	Phelps Dodge Corp.	Copper	Do.
Rabbit Creek	Nevada	Rabbit Creek Mining Inc.	Gold	Do.
Bingham Canyon	Utah	Kennecott, Utah Copper Corp.	Copper	Do.
Tyrone	New Mexico	Phelps Dodge Corp. and Burro Chief Copper Co.	do.	Do.
Bullfrog	Nevada	Bond Gold Bullfrog Inc.	Gold	Do.
Ray	Arizona	ASARCO Incorporated	Copper	Do.
Empire	Michigan	Empire Iron Mining Partnership	Iron ore	Do.
McCoy and Cove	Nevada	Echo Bay Mining Co.	Gold	Do.
Bagdad	Arizona	Cyprus Bagdad Copper Co.	Copper	Do.
Smokey Valley Common Operation	Nevada	Round Mountain Gold Corp.	Gold	Do.
Hibbing	Minnesota	Hibbing Taconite Co.	Iron ore	Do.
Pinto Valley	Arizona	Pinto Valley Copper Corp.	Copper	Do.
Mintac	Minnesota	USX Corp.	Iron ore	Do.
San Manuel	Arizona	Magma Copper Co.	Copper	Open pit and stoping.
Inspiration	do.	Cyrpus Miami Mining Corp.	do.	Open pit.
Erie	Minnesota	LTV Steel Mining Co.	Iron ore	Do.
Sierrita	Arizona	Cyprus Sierrita Corp.	Copper	Do.
Golden Sunlight	Montana	Golden Sunlight Mines Inc.	Gold	Do.
Continental	do.	Montana Resources Inc.	Copper	Do.
Jerritt Canyon (Enfield Bell)	Nevada	Independence Mining Co., Inc.	Gold	Do.
Twin Buttes	Arizona	Cyprus Sierrita Corp.	Copper	Do.
Chimney Creek	Nevada	Goldfields Mining Corp.	Gold	Do.
INDUSTRIAL MINERALS³				
Florida mines (5)	Florida	International Minerals & Chemicals Corp.	Phosphate rock	Open pit.
Florida mines (2)	do.	Agrico Chemical Co.	do.	Do.
Do.	do.	Mobil Mining and Minerals Co.	do.	Do.
Lee Creek	North Carolina	Texasgulf Chemical Co.	do.	Do.

See footnotes at end of table.

TABLE 12—Continued
**TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL¹ MINES IN THE UNITED STATES
 IN 1991, IN ORDER OF OUTPUT OF TOTAL MATERIALS HANDLED**

Mine ²	State	Operator	Commodity	Mining method
INDUSTRIAL MINERALS³—Continued				
Fort Meade	Florida	Cargill Fertilizer Inc.	Phosphate rock	Open pit.
Hookers Prairie	do.	W. R. Grace & Co.	do.	Do.
Calcite	Michigan	Michigan Minerals Associates	Stone	Open quarry.
Reed	Kentucky	Reed Crushed Stone Co.	do.	Do.
Wingate Creek	Florida	Nu-Gulf Industries Inc.	Phosphate rock	Dredging.
Stoneport	Michigan	Presque Isle Corp.	Stone	Open quarry.
Thornton	Illinois	General Dynamics Corp., Material Services Co.	do.	Do.
Marblehead	do.	do.	do.	Do.
McCook	do.	Vulcan Materials Co.	do.	Do.
St. Genevieve	Missouri	Tower Rock Stone Co.	do.	Do.
Georgetown	Texas	Texas Crushed Stone Co.	do.	Do.
Rockland	Florida	U.S. Agri-Chemicals Co.	Phosphate rock	Open pit.
Pensuco	do.	Tarmac America Inc.	Stone	Dredging.
White Rock	do.	Vecelio & Grogan Inc.	do.	Open quarry.
Mount Hope	New Jersey	Mount Hope Rock Products Inc.	do.	Do.
Calcium	Maryland	Genstar Stone Products Co.	do.	Stopping.
Granite Mountain	Arkansas	McGeorge Contracting Co., Inc.	do.	Do.
Clinton	New York	Lone Star Industries, New York Trap Rock Corp.	do.	Do.
Norcross	Georgia	Vulcan Materials Co.	do.	Do.
FEC Hialeah	Florida	Rinker Materials Corp.	do.	Do.
3 Rivers	Kentucky	Dravo Basic Materials Co., Inc.	do.	Do.

¹Excludes brines and materials from wells.

²Owing to commodity reporting difference, individual mine data may not be available.

³Includes industrial sand and gravel. Construction sand and gravel were not available for 1991 because of biennial canvassing.

TABLE 13
**TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL¹ MINES IN THE UNITED STATES
 IN 1990, IN ORDER OF OUTPUT OF TOTAL MATERIALS HANDLED**

Mine ²	State	Operator	Commodity	Mining method
METALS				
Carlin Mines Complex	Nevada	Newmont Gold Co.	Gold	Open pit.
Goldstrike	do.	Barrick Goldstrike Mines Inc.	do.	Do.
Morenci	Arizona	Phelps Dodge Corp.	Copper	Do.
Hurley	New Mexico	do.	do.	Do.
Bingham Canyon	Utah	Kennecott, Utah Copper Corp.	do.	Do.
Tyrone	New Mexico	Phelps Dodge Corp. and Burro Chief Copper Co.	do.	Do.
Bullfrog	Nevada	Bond Gold Bullfrog Inc.	Gold	Do.
Sierrita	Arizona	Cyprus Sierrita Corp.	Copper	Do.
Bagdad	do.	Cyprus Bagdad Copper Co.	do.	Do.
Pinto Valley	do.	Pinto Valley Copper Corp.	do.	Do.
McCoy and Cove	Nevada	Echo Bay Mining Co.	Gold	Do.
Minntac	Minnesota	USX Corp.	Iron ore	Do.
Hibbing	do.	Hibbing Taconite Co.	do.	Do.
Smokey Valley Common Operation	Nevada	Round Mountain Gold Corp.	Gold	Do.
Erie	Minnesota	LTV Steel Mining Co.	Iron ore	Do.
Mission Complex	Arizona	ASARCO Incorporated	Copper	Do.

See footnotes at end of table.

TABLE 13—Continued
**TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL¹ MINES IN THE UNITED STATES
 IN 1990, IN ORDER OF OUTPUT OF TOTAL MATERIALS HANDLED**

Mine ²	State	Operator	Commodity	Mining method
METALS—Continued				
Ray	Arizona	ASARCO Incorporated	Copper	Open pit.
Inspiration	do.	Cyprus Miami Mining Corp.	do.	Do.
Golden Sunlight	Montana	Golden Sunlight Mines Inc.	Gold	Do.
Continental	do.	Montana Resources Inc.	Copper	Do.
Twin Buttes	Arizona	Cyprus Sierrita Corp.	do.	Do.
Rabbit Creek	Nevada	Rabbit Creek Inc.	Gold	Do.
Jerritt Canyon (Enfield Bell)	do.	Independence Mining Co. Inc.	do.	Do.
Empire	Michigan	Empire Iron Mining Partnership	Iron ore	Do.
Candelaria	Nevada	NERCO Metals Inc.	Silver	Do.
INDUSTRIAL MINERALS³				
Florida mines (5)	Florida	International Minerals & Chemicals Corp.	Phosphate rock	Open pit.
Fort Meade	do.	Cargill Fertilizer Inc.	do.	Do.
Florida mines (2)	do.	Agrico Chemical Co.	do.	Do.
Do.	do.	Mobil Mining and Minerals Co.	do.	Do.
Lee Creek	North Carolina	Texasgulf Chemical Co.	do.	Dredging.
Hookers Prairie	Florida	W.R. Grace & Co.	do.	Open pit.
Sun Valley	California	CalMat Co. of California	Sand and gravel	Dredging.
International	New Mexico	International Minerals & Chemicals Corp.	Potash	Stoping.
Steilacoom	Washington	Lone Star Northwest	Sand and gravel	Dredging.
Southard	Oklahoma	United States Gypsum Co.	Gypsum	Open pit.
Rockland	Florida	U.S. Agri-Chemicals Corp.	Phosphate rock	Do.
Radum	California	Beazer West Inc.	Sand and gravel	Dredging.
Lompoc	do.	Manville Products Corp.	Diatomite	Open pit.
Dobson	Arizona	Salt River Sand and Rock	Sand and gravel	Dredging.
Azusa	California	Southdown Inc.	do.	Do.
Milford	Michigan	E. C. Levy Co.	do.	Do.
Perkins	California	A. Teichert & Son Inc., Teichert Aggregates	do.	Do.
Irwindale	do.	West Inc.	do.	Do.
Durbin	do.	CalMat Co. of California	do.	Do.
Retsof	New York	Akzo Salt Inc.	Salt	Stoping.
Bonanza	Nevada	Beazer West Inc.	Sand and gravel	Dredging.
Lone Mountain	do.	Nevada Ready Mix Co.	do.	Do.
Irwindale	California	United Rock Products Corp.	do.	Do.
Redlands	do.	C.L. Pharris Sand and Gravel Inc.	do.	Do.
Iowa mines (18)	Iowa	Hallett Materials Co.	do.	Do.

¹Excludes brines and materials from wells.

²Owing to commodity reporting difference, individual mine data may not be available.

³Crushed and broken and dimension stone were not available in 1990 because of biennial canvassing.

TABLE 14¹
**MARKETABLE PRODUCT AND ORE TREATED OR SOLD AT SURFACE AND
 UNDERGROUND MINES² IN THE UNITED STATES IN 1991, BY COMMODITY**

(Thousand short tons unless otherwise specified)

Commodity	Marketable product			Ore treated or sold		
	Surface	Underground	Total ³	Surface	Underground	Total ³
METALS						
Copper	1,480	228	1,710	325,000	33,200	358,000
Gold:						
Lode	4,530	4707	48,240	257,000	5,690	262,000
Placer	493	—	493	10,800	—	10,800
Iron ore	62,100	W	62,100	209,000	W	209,000
Lead	—	332	332	—	7,440	7,440
Silver	W	443	443	W	3,620	3,620
Titanium	293	—	293	W	—	W
Zinc	W	160	160	W	W	W
INDUSTRIAL MINERALS						
Barite	485	—	485	850	—	850
Boron minerals	1,320	—	1,320	1,400	—	1,400
Clays	41,100	W	41,100	44,300	74	44,400
Diatomite	672	—	672	1,950	—	1,950
Feldspar	532	—	532	951	—	951
Gypsum	13,500	1,940	15,500	13,700	W	13,700
Iron oxide pigments (crude)	33	—	33	33	—	33
Mica (scrap)	92	—	92	W	—	W
Perlite	563	W	563	652	W	652
Phosphate rock	52,800	W	52,800	172,000	W	172,000
Potash	—	1,180	1,180	—	2,150	2,150
Pumice ⁶	442	—	442	508	—	508
Salt	3,430	10,200	13,600	4,620	W	4,620
Sand and gravel	25,100	—	25,100	26,300	—	26,300
Soda ash	—	8,970	8,970	—	8,970	8,970
Stone:						
Crushed and broken	1,060,000	2,620	1,060,000	1,070,000	41,800	1,110,000
Dimension	1,090	W	1,090	2,480	W	2,480
Talc and pyrophyllite	1,130	W	1,130	1,220	W	1,220
Vermiculite	185	—	185	185	—	185

W Withheld to avoid disclosing company proprietary data.

¹This table is a compilation of previous Minerals Yearbook tables 8 and 9. Data have been integrated and reorganized.

²Excludes wells, ponds, and pumping operations.

³Data may not add to totals shown because of independent rounding.

⁴Thousand troy ounces.

⁵Short tons.

⁶Excludes volcanic cinder and scoria.

TABLE 15¹
**MARKETABLE PRODUCT AND ORE TREATED OR SOLD AT SURFACE AND
 UNDERGROUND MINES² IN THE UNITED STATES IN 1990, BY COMMODITY**

(Thousand short tons unless otherwise specified)

Commodity	Marketable product			Ore treated or sold		
	Surface	Underground	Total ³	Surface	Underground	Total ³
METALS						
Bauxite	451	—	451	537	—	537
Copper	1,521	187	1,708	321,030	21,992	343,022
Gold:						
Lode	⁴ 7,952	⁴ 379	⁴ 8,330	228,540	4,392	232,932
Placer	⁴ 83	(⁵)	⁴ 83	8,223	5	8,228
Iron ore	52,457	W	52,457	197,846	W	197,846
Lead	—	177	177	—	9,028	9,028
Silver	⁶ 175	⁶ 579	⁶ 754	2,510	3,942	6,451
Zinc	W	217	217	W	7,051	7,051
INDUSTRIAL MINERALS						
Barite	474	—	474	724	—	724
Clays	45,842	238	46,080	46,273	269	46,542
Diatomite	696	—	696	3,287	—	3,287
Feldspar	317	—	317	2,012	—	2,012
Gypsum	13,327	3,079	16,406	13,327	3,079	16,406
Iron oxide pigments (crude)	33	—	33	33	—	33
Mica (scrap)	120	—	120	303	—	303
Perlite	632	W	632	759	W	759
Phosphate rock	50,917	W	50,917	50,921	W	50,921
Potash	—	1,800	1,800	—	11,619	11,619
Pumice ⁷	488	—	488	574	—	574
Salt	2,367	10,370	12,737	2,853	15,517	18,370
Sand and gravel	932,573	—	932,573	933,206	—	933,206
Soda ash	—	4,240	4,240	—	8,195	8,195
Talc and pyrophyllite	1,365	W	1,365	1,421	W	1,421
Vermiculite	230	—	230	235	—	235

W Withheld to avoid disclosing company proprietary data.

¹This table is a compilation of previous Minerals Yearbook tables 8 and 9. Data have been integrated and reorganized.

²Excludes wells, ponds, and pumping operations.

³Data may not add to totals shown because of independent rounding.

⁴Thousand troy ounces.

⁵Less than 1/2 unit.

⁶Short tons.

⁷Excludes volcanic cinder and scoria.

TABLE 16
MINING METHODS USED IN OPEN PIT MINING IN THE UNITED STATES, BY COMMODITY, IN 1991

(Percent)

Commodity	Total material handled	
	Preceded by drilling and blasting	Not preceded by drilling and blasting ¹
METALS		
Copper	97	3
Gold:		
Lode	100	—
Placer	—	100
Iron ore	96	4
Silver	100	—
Titanium	—	100
Zinc	100	—
Average, metals ²	94	6
INDUSTRIAL MINERALS		
Barite	4	96
Boron minerals	100	—
Clays	—	100
Diatomite	8	92
Feldspar	100	—
Gypsum	95	5
Iron oxide pigments (crude)	99	1
Mica (scrap)	54	46
Perlite	67	33
Phosphate rock	3	97
Pumice ³	44	56
Salt	—	100
Sand and gravel	—	100
Stone:		
Crushed and broken	99	1
Dimension	6	94
Talc, soapstone, and pyrophyllite	87	13
Vermiculite	87	13
Average, industrial minerals ²	78	22
Average, metals and industrial minerals ³	87	13

¹Includes drilling or cutting without blasting, dredging, or mechanical excavation and nonfloat washing, and other surface mining methods.

²Includes unpublished data.

³Excludes volcanic cinder and scoria.

TABLE 17¹
MINING METHODS USED IN OPEN PIT MINING IN THE UNITED STATES, BY COMMODITY, IN 1990

(Percent)

Commodity	Total material handled	
	Preceded by drilling and blasting	Not preceded by drilling and blasting ²
METALS		
Bauxite	100	—
Beryllium	—	100
Copper	100	—
Gold:		
Lode	100	—
Placer	1	99
Iron ore	95	5
Magnesium	100	—
Mercury	100	—
Molybdenum	100	—
Silver	100	—
Titanium (ilmenite)	—	100
INDUSTRIAL MINERALS		
Aplite	100	—
Asbestos	100	—
Barite	35	65
Boron	100	—
Clays	—	100
Diatomite	1	99
Feldspar	88	12
Greensand marl	100	—
Gypsum	92	8
Iron oxide pigments (crude)	100	—
Kyanite	100	—
Magnesite	100	—
Mica (scrap)	97	3
Olivine	100	—
Perlite	4	96
Phosphate rock	3	97
Potash	—	100
Pumice ³	2	98
Salt	—	100
Sand and gravel	—	100
Talc and pyrophyllite	98	2
Vermiculite	92	8
Average ⁴	78	22

¹This table had been table 10 in the previous issue of the Minerals Yearbook.

²Includes drilling or cutting without blasting, dredging, or mechanical excavation and nonfloat washing, and other surface mining methods.

³Excludes volcanic cinder and scoria.

⁴Includes unpublished data.

TABLE 18
EXPLORATION AND DEVELOPMENT ACTIVITY IN THE UNITED STATES IN 1991, BY METHOD,
COMMODITY, AND STATE¹

(Feet)

Commodity	Exploration						Total	Development				Total
	Churn drilling	Diamond drilling	Percussion drilling	Rotary drilling	Other drilling	Trenching		Drifting, cross-cutting, or tunneling	Raising	Shaft and winze sinking	Solution mining	
METALS												
Copper	—	15,900	W	140,000	—	W	156,000	6,280	749	—	—	7,030
Gold:												
Lode	—	483,000	889,000	3,200,000	39,700	28,500	4,640,000	75,600	6,090	W	—	81,700
Placer	75	—	W	W	W	7	82	—	—	—	—	—
Lead	—	114,000	67,900	W	—	—	181,000	16,100	24,300	W	—	18,500
Silver	—	173,000	W	470	—	W	173,000	15,500	W	W	—	15,500
Zinc	—	60,900	W	—	—	—	60,900	14,700	—	—	—	17,400
Other ²	—	26,800	547,000	80,600	17,800	3,250	676,000	15,300	1,920	510	32,000	49,600
Total, metals	75	873,000	1,500,000	3,420,000	57,500	31,800	5,890,000	146,000	11,200	510	32,000	190,000
Percent of metals total ³	(⁴)	14.8	25.6	58.1	1.0	.5	100.0	77.0	5.9	.3	16.8	100.0
INDUSTRIAL MINERALS												
Diatomite	—	—	—	2,500	W	W	2,500	—	—	—	—	—
Pumice ⁵	—	—	—	90	—	—	90	—	—	—	—	—
Other ⁶	—	101,000	4,500	55,600	56,400	750	218,000	1,590	91	—	—	1,680
Total, industrial minerals	—	101,000	4,500	58,200	56,400	750	221,000	1,590	91	—	—	1,680
Percent of industrial minerals total ³	—	45.7	2.0	26.4	25.6	0.3	100.0	94.6	5.4	—	—	100.0
Grand total	75	974,000	1,510,000	3,480,000	114,000	32,500	6,110,000	148,000	11,300	510	32,000	192,000
Percent of grand total ³	(⁴)	15.9	24.7	57.0	1.9	.5	100.0	77.2	5.9	.3	16.7	100.0
STATE												
Alaska	75	W	W	W	4,000	W	4,080	W	W	—	—	—
Arizona	—	15,900	W	W	—	W	15,900	W	W	—	—	—
California	—	19,400	8	W	W	2,000	21,400	2,390	1,730	W	—	4,120
Colorado	—	14,300	W	W	W	—	14,300	4,910	1,220	W	—	6,120
Idaho	—	W	—	26,000	—	—	26,000	15,400	W	W	—	15,400
Missouri	—	W	W	—	—	—	—	7,520	—	—	—	7,520
Montana	—	3,700	12,100	144,000	—	W	160,000	W	W	20	—	20
Nevada	—	243,000	W	2,430,000	W	20,000	2,700,000	W	300	—	—	300
New Mexico	—	W	—	W	—	190	190	40	—	—	32,000	32,000
Oregon	—	3,950	—	W	—	W	3,950	W	749	—	—	749
South Dakota	—	29,000	21,000	29,000	4,700	100	83,800	35,000	3,000	—	—	38,000
Utah	—	5,950	—	W	31,000	1,200	38,200	W	W	—	—	—
Washington	—	47,000	—	30,600	—	40	77,600	—	—	—	—	—
Undistributed ⁷	—	591,000	1,480,000	815,000	74,100	9,020	2,960,000	82,500	4,280	490	—	87,300
Total, States	75	974,000	1,510,000	3,480,000	114,000	32,500	6,110,000	148,000	11,300	510	32,000	192,000
Percent of States ³	(⁴)	15.9	24.7	57.0	1.9	.5	100.0	77.2	5.9	.3	16.7	100.0

W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Data may not add to totals shown because of independent rounding.

²Includes beryllium, iron ore, platinum-group metals, tungsten concentrates, vanadium, and metal items indicated by symbol W.

³Based on unrounded footage.

⁴Less than 1/2 unit.

⁵Excludes volcanic cinder and scoria.

⁶Includes boron minerals, clays, fluorspar, gypsum, lime, salt, stone (crushed and broken), sulfur, talc, soapstone, and pyrophyllite, wollastonite, and industrial mineral items indicated by symbol W.

⁷Includes Florida, Georgia, Illinois, Minnesota, Mississippi, New York, Oklahoma, South Carolina, Tennessee, Virginia, Washington, Wyoming, and State items indicated by symbol W.

TABLE 19¹
EXPLORATION AND DEVELOPMENT ACTIVITY IN THE UNITED STATES IN 1990, BY METHOD,
COMMODITY AND STATE²

(Feet)

Commodity	Exploration							Development				Total
	Churn drilling	Diamond drilling	Percussion drilling	Rotary drilling	Other drilling	Trenching	Total	Drifting, cross-cutting, or tunneling	Raising	Shaft and winze sinking	Soluti on mining	
METALS												
Copper	—	W	—	W	—	—	W	5,600	W	4	—	5,610
Gold:												
Lode	—	432,000	415,000	1,970,000	26,500	17,500	2,860,000	94,700	7,120	W	—	102,000
Placer	W	W	—	W	—	W	W	—	W	150	—	150
Lead	9,930	157,000	85,900	—	—	—	253,000	34,900	W	W	—	34,900
Silver	—	67,400	W	8,200	W	140	75,700	10,900	6,130	1,260	—	18,300
Zinc	—	W	453,000	—	—	—	453,000	14,600	8,050	W	—	22,700
Other ³	41,500	269,000	54,400	312,000	18,000	150	695,000	18,700	4,590	720	55,600	79,600
Total, metals	51,400	925,000	1,010,000	2,290,000	44,500	17,800	4,340,000	179,000	25,900	2,130	55,600	263,000
Percent of metals total ⁴	1.2	21.3	23.2	52.8	1.0	.4	100.0	68.2	9.8	.8	21.1	100.0
INDUSTRIAL MINERALS												
Industrial minerals ⁵	21,800	117,000	21,700	100,000	73,700	33,500	368,000	5,910	118	—	—	6,030
Total, industrial minerals	21,800	117,000	21,700	100,000	73,700	33,500	368,000	5,910	118	—	—	6,030
Percent of industrial minerals total ⁴	5.9	31.8	5.9	27.2	20.0	9.1	100.0	98.0	2.0	—	—	100.0
Grand total	73,200	1,040,000	1,030,000	2,390,000	118,000	51,200	4,710,000	185,000	26,000	2,130	55,600	269,000
Percent of grand total ⁴	1.6	22.1	21.9	50.8	2.5	1.1	100.0	68.9	9.7	.8	20.7	100.0
STATE												
Arizona	—	65,700	—	W	—	150	65,900	4,320	770	W	—	5,100
California	150	27,100	W	152,000	W	2,070	181,000	12,000	1,270	150	—	13,400
Colorado	W	72,400	30,400	W	W	—	103,000	21,100	W	W	—	21,100
Idaho	—	W	W	63,800	—	—	63,800	W	W	W	—	W
Maine	—	5,000	—	—	—	—	5,000	—	—	—	—	—
Michigan	—	1,810	—	—	—	—	1,810	—	—	—	—	—
Missouri	9,930	126,000	58,500	—	—	—	194,000	W	—	—	—	W
Montana	—	W	20	167,000	—	W	167,000	W	W	—	—	W
Nevada	—	203,000	244,000	1,550,000	18,000	16,900	2,030,000	W	8,000	—	—	8,000
New Mexico	—	W	—	W	—	140	140	W	—	—	55,600	55,600
Oregon	—	2,000	—	—	—	W	2,000	W	W	—	—	W
South Dakota	—	31,000	108,000	28,800	—	—	168,000	54,500	3,670	—	—	58,100
Utah	W	W	—	W	—	2,000	2,000	W	W	—	—	W
Wyoming	—	—	47,800	118,000	—	—	166,000	—	—	—	—	—
Undistributed ⁶	63,100	508,000	542,000	316,000	100,000	30,000	1,560,000	93,500	12,300	1,980	—	108,000
Total, States	73,200	1,040,000	1,030,000	2,390,000	118,000	51,200	4,710,000	185,000	26,000	2,130	55,600	269,000
Percent of States ⁴	1.6	22.1	21.9	50.8	2.5	1.1	100.0	68.9	9.7	.8	20.7	100.0

W Withheld to avoid disclosing company proprietary data; included with "Other" or "Undistributed."

¹This table had been table 11 in the previous issue of the Minerals Yearbook.

²All data rounded to three significant digits. Data may not add to totals shown because of independent rounding.

³Includes beryllium, iron ore, platinum-group metals, tungsten, and metal items indicated by symbol W.

⁴Based on unrounded footage.

⁵Includes barite, diatomite, fluorspar, gypsum, phosphate rock, potash, salt, and talc and pyrophyllite.

⁶Includes Alabama, Florida, Illinois, Minnesota, New York, North Carolina, Oklahoma, Tennessee, Texas, Virginia, Washington, and State items indicated by symbol W.

TABLE 20
**TOTAL MATERIAL (ORE AND WASTE) PRODUCED BY MINE
 DEVELOPMENT IN THE UNITED STATES
 IN 1991, BY COMMODITY AND STATE¹**

(Thousand short tons)

	Drifting, crosscutting, or tunneling	Raising	Shaft and winze sinking	Stripping	Total
METALS					
Copper	21	1	—	W	22
Gold:					
Lode	512	22	W	241,000	242,000
Placer	—	—	—	180	180
Lead	472	7	W	W	479
Silver	121	W	W	—	121
Zinc	126	—	—	—	126
Other ²	30	21	2	81,100	81,100
Total, metals	1,280	51	2	323,000	324,000
INDUSTRIAL MINERALS					
Diatomite	—	—	—	158	158
Gypsum	—	—	—	3,820	3,823
Mica (scrap)	—	—	—	17	17
Pumice ³	—	—	—	204	204
Other ⁴	19	1	—	74	93
Total, industrial minerals	19	1	—	4,280	4,300
Grand total	1,300	51	2	327,000	328,000
STATE					
Alaska	W	W	—	180	180
Arizona	W	W	—	1,470	1,470
Arkansas	—	—	—	2,530	2,530
California	5	8	W	149	162
Colorado	88	4	W	W	92
Georgia	—	—	—	17	17
Idaho	121	W	W	550	671
Kansas	—	—	—	4	4
Missouri	363	—	—	—	363
Montana	W	W	(⁵)	W	(⁵)
Nevada	W	1	—	230,000	230,000
New Mexico	(⁵)	—	—	W	(⁵)
Oregon	W	1	—	W	1
South Dakota	70	6	—	—	76
Utah	W	W	—	11,800	11,800
Washington	237	—	—	—	237
Undistributed ⁶	417	31	2	80,400	80,800
Grand total	1,300	51	2	327,000	328,000

W Withheld to avoid disclosing company proprietary data; included with "Other" or "Undistributed."

¹All data rounded to three significant digits. Data may not add to totals shown because of independent rounding.

²Includes beryllium, iron ore, platinum-group metals, tungsten, and metal items indicated by symbol W.

³Excludes volcanic cinder and scoria.

⁴Includes fluor spar, salt, talc, soapstone, and pyrophyllite, and industrial mineral items indicated by symbol W.

⁵Less than 1/2 unit.

⁶Includes Illinois, Michigan, Minnesota, New York, North Carolina, Oklahoma, South Carolina, Tennessee, and State items indicated by symbol W.

TABLE 21¹
**TOTAL MATERIAL (ORE AND WASTE) PRODUCED BY MINE
 DEVELOPMENT IN THE UNITED STATES
 IN 1990, BY COMMODITY AND STATE²**

(Thousand short tons)

	Drifting, crosscutting, or tunneling	Raising	Shaft and winze sinking	Stripping	Total
METALS					
Copper	42	W	(³)	(³)	42
Gold:					
Lode	1,150	31	W	168,000	169,000
Placer	—	W	1	—	1
Lead	1,400	W	W	—	1,400
Silver	69	68	32	—	170
Tungsten	W	W	—	(³)	(³)
Others ⁴	295	183	3	23,800	24,300
Total, metals	3,000	282	36	192,000	195,000
INDUSTRIAL MINERALS					
Gypsum	—	—	—	7,290	7,290
Talc and pyrophyllite	W	W	—	(³)	(³)
Others ⁵	274	1	(³)	387	662
Total, industrial minerals	274	1	(³)	7,680	7,950
Grand total	3,230	282	36	200,000	203,000
STATE					
Arizona	49	5	W	—	54
California	93	3	1	W	96
Colorado	161	W	W	1,300	1,460
Idaho	W	W	W	(³)	(³)
Nevada	331	151	—	166,000	166,000
Oklahoma	—	—	—	4,170	4,170
Oregon	W	W	—	(³)	(³)
South Carolina	—	—	—	10	10
South Dakota	545	14	—	—	559
Undistributed ⁶	2,050	109	35	28,200	30,400
Total, States	3,230	282	36	200,000	203,000

W Withheld to avoid disclosing company proprietary data; included with "Others" or "Undistributed."

¹This table had been table 12 in the previous issue of the Minerals Yearbook.

²All data rounded to three significant digits. Data may not add to totals shown because of independent rounding.

³Less than 1/2 unit.

⁴Includes beryllium, iron ore, zinc, and metal items indicated by symbol W.

⁵Includes apatite, fluor spar, potash, salt, and mineral items indicated by symbol W.

⁶Includes Alabama, Arkansas, Illinois, Minnesota, Missouri, Montana, New Mexico, New York, Tennessee, Texas, Utah, Virginia, Washington, Wyoming, and State items indicated by symbol W.

TABLE 22
INDUSTRIAL EXPLOSIVES AND BLASTING AGENTS SOLD FOR
CONSUMPTION IN THE UNITED STATES,
BY CLASS AND USE, 1987-91¹

(Million pounds)

Year	Coal mining	Metal mining	Quarrying and nonmetal mining	Total mineral industry	Construction work	All other purposes	Total industrial ²
TOTAL, BY USE							
1987	3,220.8	340.3	482.9	4,044.0	308.9	145.4	4,498.3
1988*	3,137.0	440.0	595.3	4,172.3	320.2	245.0	4,737.5
1989*	3,175.0	480.0	630.2	4,285.2	330.2	190.0	4,805.4
1990*	3,200.1	499.0	640.2	4,339.3	320.2	94.3	4,753.8
1991*	2,760.4	420.0	540.1	3,720.5	260.1	96.1	4,076.7
BY CLASS AND USE							
PERMISSIBLES							
1987	33.4	—	.2	33.6	.2	—	33.9
1988*	27.0	—	.3	27.3	.2	—	27.5
1989*	22.0	—	.2	22.2	.2	—	22.4
1990*	¹ 19.1	—	¹ .2	¹ 19.3	¹ .2	—	¹ 19.5
1991*	12.4	—	.1	12.5	.1	—	12.6
OTHER HIGH EXPLOSIVES							
1987	23.2	9.0	62.3	94.4	43.4	5.5	143.2
1988*	20.0	10.0	65.0	95.0	45.0	10.0	150.0
1989*	19.0	9.0	61.0	89.0	42.0	9.0	140.0
1990*	18.0	8.0	¹ 59.0	¹ 85.0	¹ 43.0	¹ 4.8	¹ 132.8
1991*	14.0	6.0	48.0	68.0	35.0	4.3	107.3
WATER GELS AND SLURRIES							
1987	195.7	63.1	160.4	419.3	55.8	6.3	481.4
1988*	240.0	100.0	220.0	560.0	80.0	20.0	660.0
1989*	234.0	98.0	215.0	547.0	78.0	20.0	645.0
1990*	236.0	¹ 94.0	¹ 224.0	¹ 554.0	¹ 84.0	¹ 10.4	¹ 648.4
1991*	221.0	88.0	210.0	519.0	79.0	9.5	607.5
AMMONIUM NITRATE: FUEL OIL BLASTING AGENTS AND UNPROCESSED							
1987	2,968.5	268.1	260.0	3,496.6	209.6	133.6	3,839.8
1988*	2,850.0	330.0	310.0	3,490.0	195.0	215.0	3,900.0
1989*	2,900.0	373.0	354.0	3,627.0	210.0	161.0	3,998.0
1990*	2,927.0	397.0	357.0	3,681.0	193.0	79.1	3,953.1
1991*	2,513.0	326.0	282.0	3,121.0	146.0	82.3	3,349.3

*Estimated. ¹Revised.

¹Distribution of industrial explosives and blasting agents by consuming industry in 1990 and 1991 estimated from indexes of industrial production and economics reported by the U.S. Department of Energy, Federal Reserve Board, Department of Transportation, and Bureau of the Census.

²Data may not add to totals shown because of independent rounding.

ABRASIVE MATERIALS

By Gordon T. Austin

Mr. Austin, a physical scientist with more than 30 years' industry and Government experience, has been the commodity specialist for abrasive materials since 1986. The staff of the Branch of Data Collection and Coordination prepared the domestic data tables.

The combined value of production of natural abrasives, which include tripoli, special silica stone, garnet, staurolite, and emery, increased about 4% in 1990. The decrease in the value of tripoli production was the result of a decrease in total production. Emery decreased owing to a decrease in the volume of the material produced. Special silica stone experienced a decrease in unit value and in the quantity produced. Garnet showed an 8% increase in quantity and an 8% increase in unit value. Staurolite increased about 38% in the quantity produced, and the value of production increased about 36%.

The fused aluminum oxide industry showed a 12% decline in the quantity produced and a 13% decline in the value of production. The silicon carbide industry saw a 47% decrease in the quantity produced and a 23% decrease in the value of production. Combined, the industries decreased 17% in quantity and value compared with those of 1990.

The quantity of metallic abrasives sold and shipped declined 3% in quantity and 7% in value compared with those of 1990. This was after 2 stable years that had followed 4 consecutive years of increases in both quantity and value. The industry includes the primary producers of steel, chilled and annealed iron, cut wire shot and grit, and shot and grit reclaimed by primary producers. Shipments in 1991 were about 11% below the industry's high of 239,619 metric tons¹ in 1979.

The United States continued as the world's largest single manufacturer, exporter, importer, and consumer of synthetic industrial diamond. The estimated apparent U.S. consumption of industrial diamond stones was 5.0 million

carats, a decrease of 46% compared with that of 1990, but was still significantly greater than the 48-year low in 1987. (See table 1.)

DOMESTIC DATA COVERAGE

Domestic production data for abrasive materials were from seven separate, voluntary U.S. Bureau of Mines surveys. Of the 61 operations producing natural and manufactured abrasives canvassed, all responded, representing 100% of the total production shown in tables 1, 5, 6, 9, 15, 16, and 21.

FOREIGN TRADE

The total value of abrasive materials, exports plus reexports, was \$320 million, about an 8% increase compared with the 1990 value.

The total value of abrasive materials imported was \$450.9 million, a decrease of 12% compared with the 1990 value. The average total value for the past 10 years was \$381.4 million per year, with the high in 1990 of \$512.8 million and the low of \$245.0 million in 1982. Abrasive material imports had, until the 1989 decrease, increased at a compounded rate of slightly less than 13% per year for 6 years. The 1990 increase put the level of imports back on trend, but the 1991 decrease set them back below the 1988 level. The level of imports was 84% greater at the end of the period than at the beginning.

The United States has shown a trade deficit in abrasive materials for every year of the past 10 years. In 1991, the deficit decreased 40% compared with 1990's record high \$217.4 million, which

was a 43% increase from that of 1989. (See tables 2, 3, and 4.)

TRIPOLI

The category of tripoli, as broadly defined, is composed of extremely fine-grained crystalline quartz in various stages of aggregation. The particle sizes usually range from 1 to 10 micrometers, but particles as small as 0.1 to 0.2 micrometers are common. Commercial tripoli contains 98% to 99% silica and minor amounts of alumina (as clay) and iron oxide. Tripoli may be white or some shade of yellow, brown, or red depending on the percentage of iron oxide. The U.S. Bureau of Mines includes not only tripoli, but other fine-grained, porous silica materials that have similar properties and end uses such as rottenstone and novaculite. It does not include fine-grained or porous silica materials included in other Mineral Annual Report chapters, such as pumice.

Production

In 1991, the quantity of crude tripoli produced decreased 6% and the value of production increased slightly compared with those of 1990. The average production for the past 10 years was 102,356 tons per year, with a high of 112,928 tons in 1984 and a low of 88,642 tons in 1991. In the United States, four firms produced tripoli. Malvern Minerals Co., Garland County, AR, produced crude and finished material. Malvern also produces a black material from novaculite. American Tripoli Co. produced crude material in Ottawa County, OK, and finished material in

Newton County, MO. Unimin Specialty Minerals Inc.'s Alco and Tamms plants, in Alexander County, IL, produced crude and finished material. Keystone Filler and Manufacturing Co. in Northumberland County, PA, processed rottenstone, a decomposed fine-grained siliceous shale, produced by B. J. Ulrich & Sons, also in Northumberland County, PA. (See table 5.)

Consumption and Uses

Processed tripoli, sold or used, decreased 9% in quantity and 6% in value compared with those of 1990.

Tripoli is processed in mills that are jasper lined using flint or jasper pebbled in closed circuits with banks of mechanical classifiers. Materials from the mechanical classifiers are fed to micronizing mills, in which it is ground and sized at the same time. Material that is 100% minus 10 micrometers and 96% minus 5 micrometers is the smallest particle size material sold. Even this very fine particle material is not the result of fragmentation of individual crystals; instead, clusters of quartz crystals, many less than 1 micrometer in size, that are joined at their points are broken apart. The ultrafine-grained tripoli is a collection of clusters and individual quartz crystals.

Tripoli has had unique uses as an abrasive because of its hardness and its grains lack distinct edges and corners. It is a mild abrasive, making it suitable for use in toothpaste and tooth polishing compounds, industrial soaps, and metal and jewelry polishing compounds. The automobile industry uses it in buffing and polishing compounds in lacquer finishing.

The end-use pattern for tripoli has changed significantly in the past 20 years. In 1970, about 70% of the processed tripoli was used as an abrasive. Today, 70% is used as a filler and extender in paint, plastic, rubber, caulking compounds, and enamel.

The largest use of tripoli is as a filler and extender in paints. These uses are estimated to account for as much as 85% of the tripoli used as filler and extender. Its use in exterior latex paints is as a low-

micrometer-grade micronized product. In these paints, tripoli aids in tint retention, durability, leveling, and flowability. In enamels, it permits higher loading with no appreciable increase in vehicle demand and improves sheen. Because of its controlled grain or particle size, paints containing tripoli disperse easier and result in a uniform film. Additionally, because of its abrasive qualities, the paints are more resistive to wear and more resistive to chemicals than those in which water-ground whittings and other reactive fillers are used.

Plastics, rubbers, and resins each use about 5% of total annual tripoli filler and extender production. It is used extensively in plastics for electrical uses because of its dielectric properties and its effects on flexural and compressive strengths. Its chemical resistance, weatherability, and resistance to salt spray also are important to its use in plastics. Its physical properties allow high loading in most compounds, but its abrasiveness results in high wear in extruding nozzles and molds. The same properties that makes tripoli useful as a filler and extender in plastics makes it valuable to the rubber and resin industries.

Tripoli is essentially 100% crystalline silica, so its use can cause silicosis and falls under the jurisdiction of the Occupational Safety and Health Administration's (OSHA) Hazard Communication Standard. The International Agency for Research on Cancer (IARC) and other independent studies have determined that crystalline silica is a probable carcinogen for humans. As a result, OSHA is required to regulate materials containing more than 0.1% crystalline silica. To date, it does not appear that these regulations have adversely affected the use of tripoli, but all tripoli must be labeled in compliance with OSHA regulations.

In the filler and extender uses listed, ground calcium carbonate, ground silica sand, pyrogenic and precipitated silica, calcined kaolin, and talc can be substituted.

The use of tripoli as an abrasive decreased about 12% in 1991 to a 10-year low of 21,239 tons; 1991 was the seventh

consecutive year of decline. During the 7-year period, consumption declined about 43%. The average annual consumption of abrasive tripoli for the past 10 years was 29,805 tons, with a high of 37,024 tons in 1984 and a low of 21,239 tons in 1991. The 1991 consumption was the lowest since 1949, when only 20,972 tons was sold or used.

After 5 consecutive years of growth, from 1982 to 1987, the amount of tripoli used as filler declined for the fourth consecutive year. The 7% decline in 1991 followed a 10% decrease in 1990, an 8% decrease in 1989, and an additional 4% decrease in 1988. The average consumption of filler-grade tripoli for the past 10 years was 61,022 tons per year, with a high of 71,160 tons in 1987 and a low of 50,180 tons in 1982. U.S. Bureau of Mines data show that tripoli use in the United States as a filler is about 71% of the total abrasive, 29%.

Prices

The average reported value of abrasive tripoli, sold or used, in the United States was \$142.12 per ton. The average annual value reported for abrasive tripoli for the past 10 years was \$110.60 per ton, with the high value in 1991 of \$142.12 and the low in 1982 of \$76.27. The value of abrasive tripoli has increased over the past 10 years at an annual compounded rate of 10% per year. The increase has been continuous; the annual rate of increase from 1985 to 1990 was significantly lower than the annual rate of increase from 1982 through 1984.

The average reported value of filler tripoli, sold or used, in the United States was \$197.78 per ton. The average annual value for the past 10 years was \$136.33 per ton, with a high of \$197.78 per ton in 1991 and a low of \$90.81 per ton in 1982. The value increased at an annual compounded rate of about 9% for the past 10 years.

SPECIAL SILICA STONE PRODUCTS

Special silica stone products include hones, whetstones, oilstones, stone files, grindstones, grinding pebbles, tube-mill liners, deburring media, and certain specialty products. These do not include product made from artificially bonded abrasive grains. Manufacture of these products was from novaculite, quartzite, or other quarried microcrystalline quartz rock.

Production

Plants manufactured oilstones, hones, whetstones, and files in Arkansas and Indiana and cuticle stones and coaster stones in Indiana. Additional production includes grindstones in Ohio, deburring media in Arkansas and Wisconsin, and grinding pebbles and mill liners in Minnesota. Production of the crude materials was in the same State as the products manufactured.

The process for estimating production of crude material changed in 1981 and again in 1987. Because of two changes in estimating production, 10-year averages and other production trends would be of no practical use.

The production of oilstones, hones, whetstones, files, and grindstones decreased about 40% in quantity to a 10-year low of 272 tons and 43% in value to \$3.6 million. The average annual production of the products for the past 10 years was 489 tons, with a high of 647 tons in 1982 and a low of 272 tons in 1991. The average value of annual production for the past 10 years was \$5.4 million, with a high of \$7.4 million in 1987 and a low of \$3.6 million in 1991. In the past 10 years, two distinct and different trends in the value of production appeared. One was from 1980 through 1984, when the average value of production was \$4.1 million per year. The other was 1985 through 1990, when the value of production was 68% greater at an average value of \$6.9 million per year. During 1985-90, the average annual quantity of production was less than the

10-year average and the average annual value of production was 19% greater than the 10-year average. The change in average annual value was the result of a significant increase in the value per ton of manufactured products, starting in 1985. The significant decreases in 1991 can be attributed to one of the major producers in the industry entering into bankruptcy. (See tables 6 and 7.)

The industry manufactured four main grades of Arkansas whetstone. They ranged in grade from the high-quality Black Hard Arkansas Stone down to the Washita Stone. The Black Hard has a porosity of 0.07% and a waxy luster, while Washita Stone has a porosity of 16% and resembles unglazed porcelain. The four main types are shown in table 8. (See table 8.)

Arkansas accounted for essentially 100% of the value and total quantity of special silica stone products reported as sold or used by U.S. producers.

Consumption and Uses

The domestic consumption of special silica stone products is a combination of residential, industrial, leisure, and craft uses. The major residential uses were the sharpening of knives and other cutlery such as scissors, shears, and lawn and garden tools. Major industrial uses were the sharpening and honing of cutting surfaces, polishing of metal surfaces, and the deburring of metal and plastic castings. The manufacture, repair, and modification of guns also make use of stone files. The recreational uses were the sharpening of sports knives, arrowheads, spear points, fish hooks, and other recreational items. Craft applications included uses in sharpening tools for wood carving, gun engraving, jewelrymaking, and other engraving work.

Prices

The value of crude novaculite suitable for cutting into finished products varied from \$19 per ton to \$1,266 per ton. The low value was for Washita grade and the high for Black Hard Arkansas grade. The manufacture of deburring media or

special-purpose crushed stone is from material not suited for making oilstones, hones, or whetstones. The value of these materials ranged from \$11 per ton to \$440 per ton. The average value in 1991 of oilstones, hones, whetstones, and grindstones, sold or used by U.S. producers, was \$13,251 per ton. The average annual value of the same items for the past 10 years was \$11,556 per ton, with a high of \$14,741 per ton in 1989 and a low of \$6,411 per ton in 1984. In the past 10 years, the unit value of special silica stone products followed three distinct negative trends. The first trend, a gradual decrease, occurred during the period 1980-84. The value per ton averaged \$7,227, with a high of \$8,284 and a low of \$6,411 in 1984. A second trend began in 1985 when the value per ton more than doubled from \$6,411 to \$13,361. The average annual value per ton for the period 1985-88 was \$13,006, with a high of \$14,113 in 1986 and a low of \$12,229 in 1988. The third trend began in 1989, with a value of \$14,741 followed by 2 years of declining average values. One possible explanation for the series of step-ramp trends is the introduction of new high-value products by a single manufacturer. The product then encounters significant price competition from other producers in subsequent years. New products can be duplicated by competitors quickly, because the special silica stone products industry is not high technology. This very quickly results in short-term price pressures. The reason for the significant decrease in 1991 is not apparent, but may be attributed to the quality of the data.

Foreign Trade

The value of exported special silica stone products was \$7.4 million, a decrease of 29% compared with that of 1990. The average annual value of exports for the past 10 years was \$4.0 million, with a 10-year high of \$10.4 million in 1990 and a low of \$2.0 million in 1987. The annual value of exports during the past 10 years did not appear to have established a trend. Instead, the value drifted between \$2.0 million and

\$2.6 million, with as many increases as decreases until the significant increase in 1989 and 1990, followed by the 1991 decrease.

The value of imported products was \$1.8 million, a decrease of 22% compared with that of 1990, but essentially the same compared with those of 1985, 1986, and 1989. The average annual value of imports for the past 10 years was \$1.5 million, with a high of \$2.3 million in 1990 and a low of \$0.9 million in 1982. The trend for products imported to the United States was generally upward with some occasional decreases. The United States continues to be a net exporter of special silica stone products. A portion of the finished products imported was from crude novaculite produced within the United States and exported for processing.

In 1991, the trade surplus in special silica stone products was \$5.6 million, a decrease of about 31%. During the past 10 years, the United States has enjoyed an average trade surplus of \$2.5 million per year, with a high of \$8.1 million in 1990 and a low of \$0.4 million in 1985. The trend for the past 10 years has been one of declining surpluses until the 1989 and 1990 increases. The average annual surplus for 4 years before the increases had been only \$0.6 million or about 24% of the 10-year average.

GARNET

Technical-grade industrial garnet from the United States is a solid solution of almandite and pyrope that, when under pressure, breaks into sharp chisel-edged plates. Industry uses this garnet as an abrasive powder and to manufacture coated abrasives. Low-quality industrial garnet found uses primarily as airblasting or hydroblasting media and as filtration media.

Background

Definitions, Grades, and Specifications.—Garnet is a general name for a family of complex silicate minerals having similar physical properties and crystal form. The general formula for

garnet is $A_3B_2(SiO_4)_3$, where A can be calcium, magnesium, ferrous iron, or manganese and B can be aluminum, ferric iron, or chromium, or rarely titanium. The most common garnet species are $Mg_3Al_2Si_3O_{12}$ (pyrope) and $Fe_3Al_2Si_3O_{12}$ (almandite). Almandite and almandite-pyrope solid solution garnets are the best abrasive garnets, but andradite, grossularite, and pyrope also are used. Garnet displays the greatest variety of color of any industrial mineral, having been found in all colors except blue. For example, grossularite can be colorless, white, gray, yellow, yellowish green, various shades of green, brown, pink, reddish, or black. Andradite garnet can be yellow-green, green, greenish brown, orange-yellow, brown, grayish black, or black. Pyrope is commonly purplish red, pinkish red, orange-red, crimson, or dark red; and almandite is deep red, brownish red, brownish black, or violet-red. Spessartite garnet can be red, reddish orange, orange, yellow-brown, reddish brown, or blackish brown.

The Mohs hardness of garnet varies from 6.5 to 9.0. Grossularite and uvarovite have a hardness of 6.5 to 7.5; andradite is 6.5 to 7.0; and pyrope, almandite, and spessartite are 7.0 to 7.5 in hardness. There are reports of almandite having a hardness of between 8.0 and 9.0.

As with hardness, the specific gravity of garnet varies considerably. The specific gravity may be as low as 3.2 grams/cubic meter or as high as 4.3 grams/cubic meter depending on chemical composition.

Consumers purchase garnet that has been crushed, ground, and graded to different particle sizes for different end uses. Descriptions of testing methods for materials to be used in the manufacturing of coated abrasives are contained in American National Standards Institute (ANSI) Specifications B74.18-1977, "Specifications for Grading of Certain Abrasive Grains on Coated Abrasive Products."² Other specifications are contained in ANSI Specification B74.12-1976, "Specification for Size of Abrasive Grains—Grinding Wheel, Polishing, and General Industrial Uses."³

If the garnet is to be used as a sandblasting medium at a U.S. Navy shipyard or a private shipyard working on U.S. Navy vessels, then it must meet MIL-A-22262(SH) specifications that qualify it for product list QPL-22262. These specifications set forth limits on the content of total metals, soluble metals, and radiation; specify the acceptable level of chemical conductivity; and require that the material be certified by the California Air Resources Board (ARB).

ARB requires all loose-grain abrasives used in the State to be certified at the ARB testing facility. The testing is conducted according to "Methods of Test of Abrasive Media Evaluation," Test Method No. Ca 371-A, and as required under ARB's title 17, subchapter 6, entitled, "Abrasive Blasting." Copies of these documents are available from the Compliance Div. of the California Air Resources Board, Sacramento, CA. In addition, air pollution control agencies in Louisiana, Minnesota, and Utah have adopted the ARB tests and require that only ARB-certified abrasives be used on State projects requiring sandblasting. The ARB's testing procedures and standards are focused on the environmental impact of sandblasting abrasives, not on their qualities or cutting performance and/or efficiency.

The Steel Structures Painting Council, a technical organization in Pittsburgh that has a committee on abrasives, is currently drafting abrasive specification SSPC-XAB1X, "Mineral and Slag Abrasives," which will address garnet specifically. The specification defines the requirements for selecting and evaluating mineral and slag abrasives used in blast cleaning steel and other surfaces for painting and other purposes.

The American Water Works Association (AWWA) has established specification B100-89, "Standards for Filtering Materials," but this specification does not cover high-density media such as garnet and ilmenite. The AWWA plans to include garnet and ilmenite in the updated specification B100-94. In general, specifications for filtration involve garnet's particle shape, specific gravity, effective grain size, coefficient of grain

size uniformity, content of acid-soluble impurities, and content of radioactive and heavy metals.

The sale of garnet for sandblasting, water filtration, and abrasive cutting is by screen size. In U.S. sandblasting, the most widely used domestically produced garnet is $-1.0+0.3$ millimeters, followed by $-0.59+0.21$ millimeters. The most popular grade of imported garnet in the U.S. market is the $-0.59+0.25$ -millimeters grade from Australia. In U.S. multimedia water filtration systems, two grades of garnet are used, a coarse grade that is $-4.75+1.41$ millimeters, and a fine grade that is either $-0.84+0.3$ or $-0.71+0.25$ millimeters. Abrasive cutting applications' most popular grade of garnet is $-0.25+0.177$ millimeters, which may account for as much as 90% of the garnet used.

There is no definitive method for testing the quality of garnet or any other loose-grain abrasive except by actual application. There are tests and examinations that can indicate a garnet product's probable abrasive performance in use. The fracture, sharpness, shape, and structure of the garnet and the presence of inclusions all can be studied with a microscope. The hardness and friability of the garnet can be evaluated by placing a sample between two glass microscope slides and rubbing them together. The relative scratch hardness of the grains and their degree of breakdown (attrition) can be measured in this manner. Additionally, ANSI standard B74.8-1965, "American Standard Test for Ball Mill Test for Friability of Abrasive Grain," can be used to determine the friability of garnet grains.

The U.S. National Institute for Standards and Technology developed an apparatus for evaluating the abrasive quality of corundum. This tester can be adapted for use with any loose-grain abrasive. Testing of loose-grain abrasives also can be performed with various production-scale and laboratory machines where the removal of glass from flat plates is evaluated. Data from such tests can be correlated with the anticipated performance of any abrasive grain relative to the other material to be

abraded. In these tests, abrasive performance is determined by the amount of stock removed, as found either by weighing or by dimensional measurements.

In judging the abrasive quality of garnet, stock removal is not the only important factor. Surface finish is just as important. If an abrasive is too hard or contains too-coarse grains for use on a certain material it can cause deep scratches in the surface, which cannot be removed in subsequent finishing operations. Additionally, if an abrasive does not have the proper grain shape or does not break down in such a manner as to sharpen itself, it will tend to burn or gouge the material being abraded, thus defeating the purpose of its use.

ARB's testing facility tests loose-grain abrasives for certification for use in the State. The test is focused on the environmental impact of sandblasting abrasives, not on their abrasive quality.

Other firms or laboratories that test the quality of loose abrasive grains include three firms involved in the abrasive cutting industry, Flow International Corp., Ingersoll Rand Corp., and Jet-Edge, Inc., that have laboratories for testing and evaluating garnet for use in their systems. Most of the evaluations in these laboratories involve the comparative testing of various abrasive grits, including measurements of particle size distribution and mechanical properties. KTA-Tator Inc. of Los Angeles, CA, is a major consulting-engineering-testing firm whose laboratory tests and evaluates the quality of garnet and other abrasives. Much of its work is oriented to the Steel Structures Painting Council (SSPC) specifications. The SSPC also can carry out comparative testing of garnet and other loose-grain abrasives to determine whether they meet military specifications, how clean the material is, how well the material cleans, the amount of degradation during use, and other quality factors. SSPC is part of Carnegie-Mellon Research Institute and must be careful not to conduct research that favors one abrasives supplier over another supplier who may be a member of the Council.

Industry Structure.—Currently, four firms produce garnet from four plants in two States. Each domestic producer has distinctive products. The Barton Mines Corp., Warren County, NY, garnet is a mixture of almandite and pyrope and is at the top of the garnet hardness range. It occurs as large crystals and exhibits incipient lamellar parting planes that break under pressure into sharp chisel-edged plates. It retains this chisel-edged shape even when crushed to a very fine size. Its garnet is used in coated abrasives, glass grinding and polishing, and metal lapping. The NYCO Div. of Processed Minerals Inc., Essex County, NY, and International Garnet Abrasive Inc., Clinton County, NY, garnet is a mixture of andradite and grossularite, and the crude garnet concentrate may contain diopside-hedenbergite ($\text{Ca}[\text{MgFe}]\text{Si}_2\text{O}_6$). The NYCO recovered garnet as a byproduct from its wollastonite operation. It sold both crude garnet concentrate for additional refining and refined garnet for use as blasting and filtration media. International Garnet Abrasives produced refined garnet from NYCO's crude garnet concentrate for use as blasting and filtration media. Emerald Creek Garnet Milling Co. was purchased by Hawkeye Development Co., an Idaho corporation, in November 1991. Under the new name of Emerald Creek Garnet Co., it continued mining and milling operations in Benewah County, ID. Blasting and filtration media were the primary uses of the garnet.

Abrasive garnet production in the United States began in 1878 at the Gore Mountain site of Barton Mines, near North Creek, Warren County, NY. During the first year, production was less than 100 tons. It was used in coated abrasives, both paper and cloth.⁴ Barton Mines Corp. mined and processed the abrasive-grade garnet on Gore Mountain until the company moved the mining operation and processing plant in 1982 to the adjoining Ruby Mountain. Barton Mines has been a family-owned operation since its formation. Reported past domestic garnet production was from California, Connecticut, Florida, Maine,

New Hampshire, North Carolina, and Pennsylvania.⁵

Nine manufacturers at 10 plants produced garnet coated abrasive papers and cloths. The plants are in New York and Virginia, two in each, and Massachusetts, Michigan, Minnesota, Mississippi, Ohio, and Pennsylvania, one in each.

Geology-Resources.—Garnet is found as an accessory mineral in a wide variety of rocks. Most commonly it is found in gneisses and schists, but it also is found in contact metamorphic rocks, crystalline limestones, pegmatites, volcanic rocks, eclogites, and serpentinites. Additionally, garnet is found in the gangue of veins formed at high temperatures. Because garnet is resistant to chemical and mechanical weathering, it is common in the sands of current or ancestral beaches, streams, and other types of alluvial deposits. Commercially attractive industrial garnet occurrences are not common. Many garnets that occur in deposits of economic size degrade during processing because of internal stresses. These stresses developed in the garnet crystal during formation and cooling. Stress relieving is not economical; therefore, these deposits have no commercial value as a high-grade abrasive material source.

Garnets are usually small in size. Grossularite crystals range up to about 15 centimeters in diameter. Almandite approximates the same range in size except at Gore Mountain and North Mountain, NY, where crystals range up to 60 centimeters in diameter. Spessartite crystals from Brazil can weigh as much as several kilograms. Most garnet crystals are less than 2.54 centimeters in size.

The majority of world garnet production is from alluvial deposits in the United States, Australia, China, and India. Possibly the world's highest quality garnet is mined, however, from almandite-bearing rock of uncertain origin in the Adirondack Mountains of New York.

New York and Maine have the only known high-quality garnet reserves in the United States. The Wing Hill garnet

deposit, near Rangeley in western Maine, is one of the largest and highest grade garnet deposits in the world. The host rock is a homogeneous garnet granofels that consists of 50% to 70% almandite garnet. It is medium grained and consists essentially of garnet and andesine plagioclase along with biotite and minor quartz. The garnet is present as discrete, well-formed crystals from less than 1 millimeter to about 10 millimeters in diameter but averaging 1.5 to 2 millimeters. The granofels is an east-west trending, tabular body more than 1,000 meters in length and as much as 700 meters thick. The garnet ranges in Mohs hardness from 7 to 8 and in density from 3.6 to 4.3 grams/cubic meter. When crushed, the garnet breaks into blocky grains, a shape that persists down to the finest fragment. The garnet is amenable to gravity and magnetic concentration when the ore is crushed to -3.36 millimeters. The estimate of reserves in the igneous rock deposit near Rangeley, ME, is more than 1.8 million tons of garnet.

Deposits of industrial garnet are found at two locations in New York. In the Gore Mountain area, technical-grade garnet is mined as the primary product, and near the town of Willsboro, commercial-grade garnet is recovered as a byproduct of wollastonite mining.

The deposit near Gore Mountain is an almandite-bearing diorite of uncertain, igneous or metamorphic origin. The ore body is approximately 2 kilometers long and 15 to 90 meters wide. The ore grade varies from less than 5% to about 20% garnet and averages slightly less than 10%. Hornblende and plagioclase feldspar make up 40% to 80% of the host rock, while hypersthene, magnetite, biotite, apatite, and pyrite are present in minor amounts. A rough estimate suggests that more than 600,000 tons of high-quality garnet can be recovered from Barton Mines Corp's deposit on Ruby Mountain in New York. The garnet is present as imperfectly developed crystals surrounded by a rim of coarsely crystalline hornblende. The crystals range from about 1 millimeter to almost 1 meter in diameter but average about 100

millimeters in diameter. The garnet has a pronounced laminated structure, which enables it to naturally break into thin plates from about 2 to 6 millimeters in thickness. Garnet fragments maintain this platy particle shape even as they are crushed smaller and smaller.

Garnet is recovered as a byproduct from a wollastonite deposit on the western side of Lake Champlain near Willsboro. The deposit is in a belt of wollastonite-bearing rocks that is about 10 kilometers long and 0.4 kilometer wide. The largest zone of wollastonite rock within the belt is from about 9 meters to more than 20 meters thick but averages about 13 meters thick. The wollastonite is interbanded with almandite garnet and iron-rich diopside. The garnet and diopside together comprise 10% to 20% of the ore. Both the garnet and diopside are feebly magnetic and are easily separated from the wollastonite by magnetic separators.

Alluvial deposits of almandite garnet were discovered in the early 1880's near Fernwood in Benewah County, but commercial mining did not start until the early 1940's. The deposits are on Emerald, Carpenter, and Meadow Creeks about 6.4 kilometers from a mica-garnet schist formation. The source schist is estimated to be about 1,200 meters thick. The garnet-bearing gravels are from about 1 meter to about 1.2 meters thick and contain 8% to 15% garnet. Garnets from these gravels range up to 40 millimeters in diameter, although about 95% of the garnet is smaller than 7 millimeters in diameter. The quantity of garnet-bearing gravels reported at Emerald Creek and Carpenter Creek in Idaho is large. A minimum of 450,000 tons of garnet is available in the Emerald Creek Garnet Co. deposits.

There can be little doubt that tremendous reserves of garnet similar to the lower priced materials can be located as needed.⁶ Also, the production of byproduct garnet from many current mining operations is possible if demand improved.

Reserves are significant in Australia, China, India, and the U.S.S.R., but accurate data are not available. Huge

inferred and undiscovered resources are likely to exist throughout the world.⁷

Technology.—Exploration.—Successful exploration for garnet deposits begins with selection of target areas based on the presence of known favorable host rocks. Geologic studies and maps, topographic maps, and aerial photographs are used to identify favorable metamorphic, igneous, alluvial, or eolian geological formations.

The second step is field examination of the selected targets. This may include geologic mapping and limited sampling, but in many cases reconnaissance studies are sufficient. The next step, if warranted, is to sample the deposit in detail, the purpose being to measure the physical parameters of the deposit, specifically its grade and size.

The method of sampling used depends upon the type of deposit. Hard-rock deposits, igneous or metamorphic, are sampled differently than alluvial or eolian deposits.

Hard-rock deposits can be either diamond core drilled or trenched. Trenches should be oriented perpendicular to the strike of the formation and can be dug by hand, with a bulldozer, or with a backhoe.

Placer deposits can be sampled by drilling, trenching, or by excavating pits or shafts. The physical nature of the deposit, its thickness, hardness, grain size, and whether it is above or below the water table influence the method of sampling chosen. For shallow deposits, hand augers or power augers can be used to drill sample holes. In deposits that are too hard to hand auger because of the presence of clay, iron oxide cement, or mild calcium carbonate cement, two-man motor-driven augers or vehicle-mounted augers (such as post hole diggers or telephone pole hole diggers) work well. However, augering does not always provide uncontaminated samples and is not effective below the water table.

Truck-mounted water-jet drills and rotary hammer drills are used to test thick deposits and deposits that are too hard to drill with other methods. A water-jet drill uses flush-jointed drill pipe with

perforations near the bit to direct jets of water forward and downward from the bit. A hammer advances the drill bit and casing at the same time. Water from the jets flushes out the hole and returns cuttings to the surface in the annulus between the drill pipe and casing. Also, truck-mounted rotary drills equipped with double-pipe drill string and downhole hydraulic hammers can be used. Compressed air is forced down the inner pipe and returns samples to the surface in the annulus between the inner pipe and outer casing. Bits are selected depending on the type of material to be drilled.

Trenching can be carried out using either a bulldozer or a backhoe, depending on the size and depth of the deposit. In unconsolidated sediments it is difficult to maintain the stability of the walls of trenches, and samples can be contaminated by material sloughing from above. Bulk samples can be collected from 1-cubic-meter pits or shafts. However, here again, wall stability can be a problem unless some form of shoring is used.

Evaluation of Deposits.—The evaluation of garnet deposits to determine their suitability for commercial production can be divided into five major factors: (1) size and grade of the reserves; (2) mining conditions; (3) quality of the garnet; (4) location of the deposit relative to markets and infrastructure; and (5) milling costs. The relative importance of each of these factors will vary from one deposit to another, but the final determination of economic viability will depend upon all of them.

1. Size and grade of reserves—An economic garnet deposit has reserves that are large enough and high enough in grade to provide full project capital recovery, meet all operating costs, and furnish a reasonable profit over the depreciable life of the project, which is normally at least 10 to 20 years. Generally, a deposit should contain a minimum of 2 million tons of ore. The cutoff grade used in calculating reserves will depend on the economics of the

specific deposit, but cutoff grades for most deposits average about 20% garnet.

2. Mining conditions—Mining conditions greatly affect the economics of a deposit and can even control whether the deposit can be developed. Early field examinations should identify any conditions, such as nearby houses, historical sites, national monuments, archeological or paleontological sites, wildlife refuges, municipal watersheds, etc., that could preclude mining the deposit. Local, county, and State zoning regulations, environmental regulations, and other constraints should be checked to establish their effects on mining the deposit.

Hard-rock garnet deposits are mined in benched open pits using conventional drill-and-blast methods. Some placer deposits are mined with dredges. The configuration and structure of the deposit should be such that there are no blocks of waste rock within the ore body and that the garnet is, ideally, uniformly distributed throughout the ore. All physical and chemical features of the ore and overburden will influence whether the deposit is amenable to open pit mining and will impact the total mining cost per ton.

3. Quality of the garnet—The garnet in a deposit must be tested to evaluate its performance and marketability as an abrasive. It should be recognized in this regard that most garnet used in abrasive applications is either the almandite or almandite-pyrope type. The garnet should be present in the deposit as discrete crystals that are at least 6 to 13 millimeters in size and that are liberated when the ore is crushed to -2 millimeters. The crystals should be free of any inclusions, such as quartz, mica, hornblende, and feldspar, and also should be free of alteration. The garnet should be relatively uniform in hardness and density throughout the deposit. It should not be badly weathered or highly friable. If an incipient parting is present in the garnet crystals, the effect this parting has on the quality of the final product and the distribution of such crystals within the deposit should be determined.

4. Location relative to markets and infrastructure.—The location of a garnet deposit must be evaluated relative to its proximity to the markets for garnet abrasives and filter media. If the deposit itself is not near major market areas, then it must be near adequate and inexpensive means of transportation, especially by rail or water. Deposits should be reasonably accessible from existing roads.

5. Milling costs—The type of milling required and the cost of processing the ore must be analyzed carefully. Ideal ore is that from which the garnet can be liberated with minimum crushing and can be recovered using gravity/density-based methods of mechanical concentration and where size classification of the concentrate yields a complete range of product sizes. In some cases portions of the concentrate will be ground to achieve proper particle size distribution.

Mining.—At the Barton Mine in New York, the Ruby Mountain ore body covers approximately 41,000 square meters, which is nearly the entire mountain. The ore is mined by open pit methods with benches 9 meters high. The ore is drilled and blasted, a drop ball provides secondary breakage, and power shovels load ore into trucks for haulage to mill, about 0.4 kilometer away.

At Emerald Creek and Carpenter Creek, Benewah County, ID, backhoes are used to strip 1 to 2 meters of overburden to expose the garnetiferous gravel. Mining is then carried out with draglines, and ore is trucked to a mill for processing.

Wollastonite mining at Willsboro, NY, yields a byproduct concentrate containing garnet, diopside-hedenbergite, and minor amounts of wollastonite. After drilling, blasting, and loading, the ore is transported 22 kilometers to the plant for separation of the wollastonite from the garnet-diopside.

Beneficiation.—The primary factors controlling the behavior of garnet ore during processing are the identity and characteristics of the minerals present, the percentage of each mineral present, and the size of the garnet grains. The major minerals associated with garnet in most

deposits are feldspar, mica, hornblende, pyroxene, and quartz. Magnetite, pyrite, ilmenite, limonite, pyrrhotite, and occasionally chalcopyrite, rutile, zoisite, chlorite, and corundum may be present in much smaller amounts. Sodium feldspar is the most common feldspar, biotite is the most common mica, and hypersthene and diopside are the most common varieties of pyroxene present. The most important physical property controlling the behavior of the major and minor minerals during concentration of the garnet is their specific gravity.

At Barton Mines Corp.'s plant in New York, garnet is liberated, concentrated, and further processed by combinations of crushing and grinding, screening, tabling, flotation, magnetic separation, water sedimentation, drying, heat treating, and air separation. Occasionally a single process will accomplish both sizing and the removal of gangue minerals, but this usually requires several processes. Particle size control can be difficult but is important in order for the concentration processes to work effectively.

The process used by Barton Mines to recover garnet has evolved over time. It began in 1924 with construction of the first "modern" plant where separation was accomplished using jigs. In 1941, heavy-media separation was added to the system, and in 1945, flotation was added. The current state-of-the-art mill is a combination of heavy-media and flotation circuits. Ore crushed to -7 millimeters is screened to 3.36 to 2.38 millimeters with the coarse fraction going to a heavy-media circuit using a density of 3.02 grams/cubic meter for primary separation and a density of 3.20 to 3.40 grams/cubic meters for secondary separation. The fine fraction from the screen goes to a flotation circuit where it is first ground to -0.3 millimeters in ball mills and then fed to float cells. The concentrate from the heavy-media circuit is roll crushed, combined with the float concentrate, and then dried and heat-treated in a rotary kiln.

At Emerald Creek Garnet Co.'s operation in Idaho, the ore is first processed through trommels to remove the gravel and is then concentrated in jigs

and on shaking tables. The garnet concentrate is dried, crushed, and screened. The maximum grain size of finished products is 46 millimeters.

At NYCO Minerals' mill in New York, beneficiation of the wollastonite-garnet ore requires two stages. The first stage involves drying, crushing, screening, and recrushing the feed to -1.19 millimeters. In the second stage, the -1.19 millimeter ore passes over a series of screens to attain -1.19+0.84, -0.84+0.42, -0.42+0.25 and -0.25 millimeter splits. A battery of magnetic separators then removes the garnet from each of these fractions. Four sizes of final product are bagged for shipment.

Today practically all grade-grain abrasive garnet is heat treated as a processing function, but not to improve its inherent abrasiveness. Impurities picked up during processing stick to the garnet particle surfaces. These impurities destroy the cleanliness and capillarity needed in later processing to give adhesion for bonding. In the early 1960's, scientific investigations determined that heat treating only cleaned the particle surfaces and that too high a temperature could destroy the abrasive quality of garnet. In the mid-1960's, the coated abrasive industry accepted uniform color standards. These standards ensured the cleanliness of the grain surface and a color most closely approaching the natural red color of abrasive garnet. The heat treatment needed to do this is the RT treatment.⁸

Annual Review

Production.—In 1991, the four U.S. firms produced 50,860 tons of crude garnet concentrate worth \$7.5 million, an 8% increase in quantity and salient statistics compared to those of 1990. The average annual production for the past 10 years was 36,262 tons, with a high of 50,860 in 1991 and a low of 24,769 in 1982. During the past 10 years, production increased about 105%, or at an annual compounded rate of about 8.5% per year. The production trend for the past 10 years has been one of

continued long-term growth with two downward adjustments. (See table 9.)

Consumption and Uses.—In 1991, the quantity of garnet sold or used by producers was 48,048 tons, an increase of 5%, and the value increased about 11% to \$13.0 million. The average annual quantity of garnet sold or used for the past 10 years was 34,488 tons, with a record high of 48,048 tons in 1991 and a low of 24,186 tons in 1982. The trend for the past 10 years was one of steady annual growth, except for 4% decreases in 1984. The growth rate averaged about 8% compounded annually.

The major industrial use for high-quality, high-value garnet since before 1880 has been as loose-grain abrasive for applications such as optical lens grinding and plate-glass grinding. In recent years, its applications included the high-quality, scratch-free lapping of semiconductor materials and other metals. The finishing of wood, leather, hard rubber, felt, and plastics often requires the use of garnet-coated abrasive papers and cloths.

The aluminum aircraft and shipbuilding industries in California and the Pacific Northwest use lower quality, lower cost alluvial garnet, primarily from Idaho, for sandblasting. Similar uses in the Eastern United States are for the cleaning and conditioning of aluminum and other soft metals and for cleaning of metal by structural steel fabrication shops. Mixed-media water filtration, using a mixture of sand, anthracite, and garnet, has displaced older filtration methods because it is more reliable and gives a better quality of water. Garnet also is used in hydrojet cutting—it is entrained in a high-pressure stream of water to cut many different materials. Demand for these uses has greatly increased. The manufacturers of nonskid floor paint also use alluvial and other low-cost garnets.

Garnet has obtained an intermediate place in the coated-abrasive field between low-cost quartz sand and more costly synthetic abrasives (silicon carbide and fused alumina). Garnet is reportedly more efficient based on unit production costs than quartz sand. It also produces a more

desirable finish on items made of wood, leather, hard rubber, felt, and plastic.

Garnet, especially the lower grades, cannot compete with synthetic abrasives for most metalworking applications requiring substantial metal removal because of its friable nature and lower hardness.

Prices.—The average value per ton of crude garnet concentrates was \$148, a 17% decrease compared with the 1990 average. The average value for the past 10 years was \$111 per ton, with a high of \$178 in 1990 and a low of \$88 per ton in 1986. During the past 10 years, the trend for the value of crude concentrates was one of general increase with decreases in some years. The 1991 value was 157% of the 1982 value.

In 1991, the average value per ton of garnet sold or used was \$271, an increase of 6% from that of 1990. The average value for the past 10 years was \$237 per ton, with a high of \$271 in 1991 and a low of \$216 per ton in 1987. The price trend of garnet sold or used during the past 10 years has been one of stable prices with very minor changes, except the 23% increase from 1987 to 1988.

Foreign Trade.—Garnet exports, as reported to the U.S. Bureau of Mines, by producers were about 10,000 tons, essentially the same as those for 1990. Export data on garnet were not available from the Bureau of the Census (Department of Commerce). Producers have reported exports to the U.S. Bureau of Mines for the past 5 years. According to reports by producers, exports increased significantly during the past 10 years.

Mineral brokers and other garnet importers reported to the U.S. Bureau of Mines about 5,000 tons of imported garnet, unchanged from those of 1989 and 1990. Import data for garnet also were not available from the Bureau of the Census. U.S. Bureau of Mines data, which are available for only 5 years, showed garnet imports as stable for the past 3 years. The United States was a net exporter of garnet in 1991; exports exceeded imports by 100%.

World Review.—The United States was the dominant world producer and consumer of garnet, accounting for approximately 45% of the estimated world output and almost 40% of estimated world consumption. Target Mines Ltd. (a subsidiary of Barton Mines) continued to produce at near capacity from its Australian garnet sand operation. The Chinese mines continued to increase production of garnet for the domestic and world market. Two mineral sand mining operations in India continued to produce garnet as a byproduct of mineral sands production. Turkey and the U.S.S.R. primarily produce for local markets. (See table 10.)

Outlook

The U.S. production and consumption of industrial garnet during the next 5 years will be a function of the installed capacity. Currently, the industry is operating at or near capacity. If capacity can be added, production and consumption will increase to approximately 60,000 tons per year by 1996. If garnet were not available, other abrasives could be used in its place, but in many cases with some sacrifices in work volume, quality of work, or cost.

Substitution of other natural and synthetic material is present to some extent for all major end uses of garnet. Fused alumina and staurolite compete with garnet as a sandblasting material in the transportation equipment industries. Ilmenite and plastics compete as filtration media. Diamond, corundum, and fused alumina compete for lens grinding and for many lapping operations. Finally, sand, silicon carbide, and fused alumina compete for grinding and finishing of plastics, wood furniture, and other products.

EMERY

Emery is a gray to black rock containing various minerals, including corundum, magnetite, hematite, or hercynite, and trace minerals such as mullite, titania, silica, and magnesia. Its hardness ranges between 7 and 9 on the

Mohs' scale and its specific gravity ranges from 3.2 to 4.5, depending upon its composition. It is used as an abrasive aggregate for nonskid, wear-resistant floors, pavements, and stair treads; as tumbling or deburring media; and in the manufacture of coated abrasives.

Production

A single firm, Oregon Emery, Albany, OR, produced emery in 1991 using open pit mining methods. The U.S. production of emery decreased about 81% in quantity and value compared with those of 1990. Production from the historical emery producer near Peekskill in Westchester County, NY, stopped in 1988. The emery mine was sold to a firm that converted the mine into a crushed stone quarry.

Consumption

The Bureau estimated that the United States consumed approximately 10,000 tons of emery in 1991. Imports from Greece and Turkey accounted for most of the material consumed. Four firms processed and distributed emery for domestic consumption: Washington Mills Abrasives Co., Emery-Crete Inc., Oregon Emery, and General Abrasives Co.

Foreign Trade

The United States did not export emery in 1990, nor has it done so in the past 10 years. During the past 10 years, the United States may have reexported a small amount of emery. The Bureau of the Census reports emery imports, exports, and reexports in mineral group categories; thus, exact data on emery are not available.

World Review

Turkey was the world's largest producer of emery. Its production is handled by Etibank in Ankara, by Ranar Minerals Industries Corp. in Istanbul, and by Lutfullah E. Kitapci Minerals Co., Ltd. in Izmir. Total production in 1991 was about 25,500 tons. Prices of Ranar

emery ranged from \$34 to \$48 per ton for crude and from \$220 to \$460 per ton for micronized grades.

The second largest producer was Greece. In Greece, government-owned deposits on the Island of Naxos are worked by villagers. It is estimated that 1991 production was about 10,000 tons.

STAUROLITE

Staurolite is a naturally occurring, complex, hydrated aluminosilicate of iron having a variable composition. The mineral most commonly occurs as opaque, reddish-brown to black crystals. It has a specific gravity ranging from 3.74 to 3.83 and Mohs' hardness of between 7 and 8.

Production

Georgia, North Carolina, and Virginia produced mineral specimen staurolite crystals. The crystals were in the cruciform twinned form commonly called "fairy crosses." E.I. du Pont de Nemours & Co. Inc. produced industrial-grade staurolite in Florida. Publishing production data would disclose company proprietary data; but, production of industrial staurolite increased 38% in quantity and 36% in value compared with those of 1990.

Industrial staurolite was a byproduct of heavy-mineral concentrates recovered from a beach sand deposit in Clay County, north-central Florida. Electrical and magnetic separators remove staurolite from the concentrates after scrubbing, washing with caustic, rinsing, and drying. The resulting material was about 77% clean, rounded, and uniformly sized grains of staurolite, with minor amounts of tourmaline, ilmenite and other titanium minerals, kyanite, zircon, and quartz. A nominal composition of this staurolite sand is 45% aluminum oxide (minimum), 18% ferric oxide (maximum), 5% silica (maximum), and 3% zirconium dioxide (maximum).

Consumption

During 1991, shipments of staurolite increased 30% in tonnage and 29% in value compared with those of 1990. Staurolite, marketed under the trade name Biasill, was used as molding material in nonferrous foundries because of its low thermal expansion, high thermal conductivity, and high melting point. Its low softening temperature often restricts its use to nonferrous casting. The major use of staurolite was as an abrasive for impact finishing of metals and sandblasting of buildings. The blasting media trade names were Starblast (80 mesh) and Siasill (90 mesh). A coarse grade (55 mesh) also was used as an abrasive. Some portland cement formulations consumed a minor amount. As regulations limiting the amounts of free silica in airblasting media became more stringent, the demand for staurolite increased.

Foreign Trade

Neither the Bureau of the Census nor the staurolite industry reported any exports or imports of staurolite. Given the limited market and the low price per ton, no international market for staurolite should develop in the near term.

World Review

India continued to produce small amounts of staurolite for local consumption. Other countries sometimes produce small amounts of staurolite as a byproduct of mineral sands or gemstone production.

INDUSTRIAL DIAMOND

Industrial diamond is natural diamond that does not meet the standards of gem diamond because of its color, size, or other imperfection. Also, it may be a synthetic diamond that is tailor-made for industrial applications.

Background

Definitions, Grades, and Specifications.—Natural industrial diamond is diamond that, because of color, structure, size, or shape, is unsuitable for use as gemstones. Major categories are industrial stones (die stones, tool stones, and drilling stones), crushing bort, and grit and powder. The distinction between stone and grit is not well defined; generally, the dividing line is a range of sizes. Stones usually are particles larger than 16 to 20 mesh, grit from 16 to 20 mesh to 325 to 400 mesh, and powder as particles smaller than 325 to 400 mesh. These categories are subdivided further into more than 100 groups.⁹

Bort is natural diamond that occurs in finely crystalline aggregates and usually is crushed into finer material. Originally, the term was the name for all crystalline diamonds not usable as gems. Later it designated those diamonds not usable as gems, tool stones, die stones, or drill stones. Currently, the term refers to low-grade industrial diamond suitable only for use in a fragmented form.

Most synthesized diamond marketed to date is 20 to 30 mesh and smaller. Recently, producers began to manufacture synthetic stones of 2 carats or larger. Marketing of these stones to date is of engineered pieces of the stones, not the entire stone. Polycrystalline synthetic diamond compacts and shapes can replace some larger stones. There are several types of synthetic diamond. They range from very friable material with a highly irregular shape to blocky, regular shapes with excellent crystal structure. The manufacture of industrial diamond stones is not commercially viable.

The metric carat, 0.2 gram, is the unit of measure for industrial diamond. One pound contains 2,268 carats, and 1 kilogram contains 5,000 carats. The carat is equal to 100 points. Diamond grit and powder sizes are identified by U.S. standard screen classifications, by ANSI Specification B74.16-1971,¹⁰ ANSI Specification B74-20-1981,¹¹ and by a proposed standard developed by the Industrial Diamond Association¹² for

subsieve micron-sized diamond or cubic boron nitride powders. The terms "sand," "grit," and "powder" also describe decreasing orders of fine diamond.

Machine-shop waste containing diamond is sludge if obtained from wet grinding and is called swarf if obtained from dry grinding.

Industry Structure.—The original discoveries of diamond in India, Borneo, and Brazil, and later in South Africa, were due to chance finds by local inhabitants. Certain desirable characteristics in diamond were noted first in India and led to active search by open pit workings and to concentration by hand methods.

Probably the first industrial use of diamond was as diamond powder for polishing gem diamonds and other precious stones. The art of diamond cutting and polishing was known in India, probably well before A.D. 1400.

Glasscutting was an early application of diamond in industry. It was the most important use of industrial diamond until the 1860's.

England issued a patent in 1819 for drawing wire through a diamond die. Diamond wiredrawing dies gave close dimensional accuracy to wire, even after long periods of use.

The use of diamond for metalcutting began in the 1860's, but the high price of diamond tools was a drawback to their acceptance. As the economic advantages of using diamond tools became known, demand increased rapidly.

The use of the first diamond drill was in 1864. The discovery of diamond in South Africa in 1867 provided ample supply for the new and growing demand for diamond drill bits.

With the introduction of cemented tungsten carbide cutting tools during World War I, industrial diamond use increased. The cause of the increase was that diamond was the most effective agent in grinding tungsten carbide. Requirements for industrial diamond expanded tremendously because of World War II, when demand increased for grinding wheels, die stones, tool stones, drill bits, dresser stones, and polishing

dust. The apparent supply of industrial diamond decreased rapidly following World War II.

In 1955, General Electric Co. announced the development of a process for the manufacture of diamond at its Schenectady, NY, laboratories. Commercial production started in 1957 at its plant in Detroit, MI. In 1969, production moved to Worthington, OH. In 1959, De Beers Consolidated Mines Ltd. announced the manufacture of industrial diamond at its laboratory in Johannesburg, Republic of South Africa. Since these two announcements, the production of synthetic diamond by General Electric, De Beers, and others continued to increase. Today it exceeds the production of natural diamond worldwide about five times.

Geology.—The major source of in-place diamond is kimberlite, an altered, darkgreen basic rock of igneous origin. Throughout the world there are approximately 1,000 occurrences of kimberlite, but most do not contain diamonds or do not contain diamonds in economic quantities. The term "diamond pipe" refers to an occurrence of kimberlite large enough and sufficiently diamondiferous to be mined. The size and shape of these pipes depend on the manner in which molten kimberlite passed through the country rock. They may be columnar, tabular, or irregular in shape. Where mining is deep enough, the diamond pipe always decreases in area and assume a dikelike habit. The diamond may contain inclusions of many minerals, and many of these minerals have inclusions of diamond. These accessory minerals include olivine, garnet, diopside, ilmenite, magnetite, rutile, and phlogopite. Every mine has some diamond that is typical of it, but most diamond is indistinguishable from that of other mines.

Currently, approximately 40% of diamond is from alluvial deposits. These may be alluvial placers, recent or elevated marine beach placers, or glacial deposits. Often the distance of transport has been great. In many areas, the diamond-bearing, alluvial placers were

deposited in former drainage systems unrelated to any present system.¹³

Technology.—Mining.—Currently, the United States has no commercial deposits of diamond. In other countries, mining methods range from very crude hand mining and panning to block caving of kimberlite pipes. Large-scale surface mining operations in Australia, Zaire, Angola, Namibia, and Sierra Leone¹⁴ use modern equipment, such as continuous bucket wheel excavators, power shovels, draglines, scraper-loaders, and motor trucks, to remove overburden and to mine and transport the diamond ore.

Processing.—The type of ore, size of operation, and other factors decide the types of processing equipment used. Crushing, where necessary, is done mostly with gyratory and roll crushers to avoid impact to diamond stones. Additional grinding is done with attrition and ball mills to further separate the gangue from diamond stones. Clayey ore may require the use of log washers. Diamond washing pans, jigs, heavy-medium separators, or hydrocyclones collect the primary or intermediate concentrates. Depending on the types, shapes, and sizes of diamond present, various final treatments are used. They include the use of grease tables and grease belts, electromagnetic separators, electrostatic separators, optical sorters, X-ray sorters, and other devices. In all processing plants, hand sorting is the final recovery process.¹⁵

Reclaiming industrial diamond stones from drill bits and grit from the wastes generated in grinding, sawing, and other operations is common. This is because of the high unit value of diamonds. Reclamation processes include physical methods such as distillation to remove coolants and lubricants, followed by electrostatic, magnetic, or flotation separation. Reclamation also uses chemical methods, including combustion, acid treatment, and fusion with alkalis.¹⁶ The treatment used depends primarily on the contaminants present.

Commercial production of synthetic diamond grit is by two basic methods.

Currently, the primary method used involves the application of ultrahigh pressure and high temperature to carbon-metal catalyst mixtures by powerful hydraulic presses. This method uses pyrophyllite and other materials for the reaction vessel. Pyrophyllite for this purpose is from the Republic of South Africa, where the local name for it is wonderstone. The major user of the method now uses synthetic reaction-vessel materials, alleviating the dependency on foreign sources for pyrophyllite. The material used for these replacement reaction vessels is proprietary. The other method employs explosive shock to the carbon-metal catalyst mixtures.

Industrial diamond particles of good quality up to 20 mesh and perhaps larger are produced. The shape and other characteristics can be controlled by proper manipulation of the variables, pressure, temperature, time, and catalyst type. Only micrometer-size particles are presently available from the explosive process. Other methods of diamond synthesis exist, but none are in commercial use in the United States. Other countries produce diamond grit; all of these apparently use the ultrahigh-pressure, high-temperature method involving hydraulic presses.

Polycrystalline synthetic diamond compacts are a laminated structure of synthetic diamond powder bonded to a cemented carbide substrate. Their production is by a proprietary high-pressure, high-temperature process that gives the product excellent uniform physical properties.¹⁷

The polycrystalline synthetic diamond shape is a dense, nonporous, fully intergrown product that is thermally stable to 1,200° C. Production uses a proprietary high-pressure, high-temperature process using a special binder phase that is retained as an integral part of the product and results in high resistance to shock loading.¹⁸

Annual Review

Government Programs.—The National Defense Stockpile (NDS) for industrial diamonds, as of December 31, 1991, had a goal of zero carats and an inventory of 14.0 million carats for crushing bort. The goal for industrial stones was 7.7 million carats, and the inventory was 7.78 million carats. There was 5 million carats of sales of crushed and crushing bort diamonds from the stockpile during 1991. There is currently legislative authority for disposal of 19,617 carats of bort and 2,400,000 carats of industrial stones, but there were no disposals of stones during the year. The inventory of small diamond dies was 25,473 pieces compared with a goal of 60,000 pieces; but, no purchase authorization was issued.

Production.—The United States was the largest producer of synthetic industrial diamond. This has made the United States independent of foreign sources for crushing bort or similar diamond except for grit sizes larger than about 20 mesh. Having no production of natural diamond, it was dependent on other countries for its natural diamond supply.

Three domestic firms produced synthetic industrial diamond in the United States: Du Pont Industrial Diamond Div., Gibbstown, NJ; General Electric Co., GE Superabrasives, Worthington, OH; and Megadiamond Industries Inc., a subsidiary of Smith International Inc., Provo, UT. A fourth company, U.S. Synthetics Corp., Orem, UT, manufactured polycrystalline diamond from purchased synthetic diamond grit. U.S. Synthetics had the capability to manufacture synthetic industrial diamond grit, but chose not to for economic reasons. Publishing production data would disclose company proprietary data. Domestic production did increase significantly. The United States continued to be the largest single producer of synthetic industrial diamond, a role it has enjoyed since 1957. During the past 10 years, production increased at an average rate of 9% compounded annually.

U.S. secondary production of industrial diamond was from six firms. They were Amplex Corp., Bloomfield, CT; Diamondsharp Corp., Keene, NH; Industrial Diamond Laboratory Inc., Bronx, NY; Industrial Diamond Powders Co., Pittsburgh, PA; International Diamond Services Inc., Houston, TX; and National Research Co., Fraser, MI. The firms reclaimed a total of about 3.8 million carats from used drill bits, diamond tools, and wet and dry diamond-containing waste, a decrease of 41% compared with that of 1990.

Consumption and Uses.—The United States continued to be the largest single consumer of industrial diamond. The U.S. Bureau of Mines estimate of apparent consumption of industrial diamond was approximately 86 million carats, an increase of about 19% compared with 1987 consumption. Average annual consumption for the past 10 years was about 64.1 million carats. During this period, two different trends for consumption occurred. The average annual consumption for 1979-83 was about 37.5 million carats, whereas that for 1984-88 was 97% greater or about 73.9 million carats. The second trend was the result of the strong movement to industrial diamond in the U.S. manufacturing sectors. This was because of the economic advantages in removing material and finishing surfaces using industrial diamond and diamond tools and wheels. Additionally, the continued economic growth of the U.S. industrial sector affected demand.

Diamond is far harder than any other natural or artificial abrasive material; so it was essential for some uses and much more efficient than other abrasives for many others. The principal uses of industrial diamond stones are in drilling bits and reaming shells, single- or multiple-point diamond tools, diamond saws, diamond wheels, abrasive, and diamond wire-drawing dies. Miscellaneous uses include: engraving points, glass cutters, bearings, surgical instruments, and special tools. Changes in technology and conventional wisdom have resulted in an increased use of synthetic

industrial diamonds and polycrystalline diamond shapes (PDS) and compacts (PDC) for many of the uses listed above. There has been an increased use of PDS, PDC, and matrix set synthetic diamond grit in drilling bits and reaming shells in the past 3 years. Diamond saws, diamond wheels, and diamond abrasive grit and powder are almost exclusively made from synthetic diamond. PDS and PDC are used in the manufacture of single- and multiple-point tools, and PCD is used in a majority of the diamond wire-drawing dies.

Mineral, oil, and gas exploration were the primary uses of drilling bits and shells. Foundation testing for dams, buildings, and other construction also used diamond bits and shells, as did masonry drilling in buildings for conduits and access and testing of concrete in various structures and other similar applications. The primary uses of diamond tools were for dressing and trueing grinding wheels and for cutting, machining, boring, and finishing. Beveling glass automobile windows also was a use. Cutting dimension stone, ceramics, and concrete in highway reconditioning were the major uses of diamond saws. The forming of refractory shapes for furnace linings also uses diamond saws. Diamond wire dies were essential for high-speed drawing of fine wire, especially from hard, high-strength metals and alloys.

Diamond grit, powders, and fragmented bort go into diamond grinding wheels, saws, impregnated bits and tools, and loose abrasives compounds for lapping and polishing.

Three major types of grinding wheels were made—resinoid, metal, and vitrified bonds—in many shapes and sizes designed for specific applications. The sizes range up to 1 meter in diameter for very large industrial wheels. Sharpening and shaping of carbide machine tool tips, grinding of dies, edging of plate glass, and optical grinding were among the primary applications of diamond grinding wheels. The cutting of concrete, stone, ceramics, and composite materials were uses of saws made with diamond grit. Very fine saws sliced wafers from brittle

metals and crystals for use in electronic and electric devices.

Finishing optical surfaces, jewel bearings, gemstones, wire-drawing dies, cutting tools, and metallographic specimens were the primary uses of polishing and lapping powder and compounds. Hundreds of other important items made from metals, ceramics, plastics, and glass also were finished with diamond compounds.

Prices.—The U.S. Bureau of Mines does not collect price data on industrial diamonds. The Bureau did track the average import value of various classifications of industrial diamonds. The average value of U.S. imports of natural grit and powder, synthetic grit and powder, and industrial stones was \$0.63 per carat, \$0.74 per carat, and \$6.94, respectively. The average annual value of imported natural grit and powder for the past 10 years was \$1.64 per carat. The high value was \$2.85 in 1980, and the low was \$0.82 in 1988. The average value of natural grit and powder, in current dollars, declined every year since 1980. The 1980 average value was 425% greater than that of 1988.

The average annual value of imported synthetic grit and powder for the past 10 years was \$1.30 per carat. The high value was \$1.86 per carat in 1981, and the low was \$1.08 in 1988. The average value of imported synthetic grit and powder decreased every year since 1981. The 1988 value declined 72% compared with that of 1981, while the decline from 1987 to 1988 was only about 26%. During the past 10 years, a major change occurred in the relationship of the average value of natural grit and powder to the average value of synthetic grit and powder. In 1979, natural grit and powder average value was 49% greater than the average value for the synthetics. In 1988, the average value for the synthetics was 32% greater than that for natural material. Natural grit and powder declined in value at a much greater rate than did synthetic grit and powder. This made the synthetic material more valuable.

The average annual value of imported industrial diamond stones for the past 10 years was \$9.19 per carat, with a high value of \$13.93 in 1981 and a low of \$7.24 in 1986. The trend for the value of industrial stones was mixed for the past 10 years. There was a small, 7%, decrease in the average value. The period started with 3 years of increasing values, followed by 3 years of decreasing values. Values the final 4 years were alternating decreases and increases. The 1988 average value was 5% less than the 1987 value, 44% less than the 1981 high, and 12% less than the 1979 value.

Foreign Trade

The United States was the largest exporter of industrial diamond grit and powder in the world. The United States exported and reexported a record 78.8 million carats of natural and synthetic grit and powder. The material was worth a record \$119.3 million. Additionally, the U.S. exported and reexported approximately 2.9 million carats of industrial stones valued at \$21.7 million.

Six countries received approximately 76% of the total U.S. exports of synthetic grit and powder. The countries and the percentage of exports they received were as follows: Japan, 27%; Federal Republic of Germany, 21%; Ireland, 8%; Italy, 7%, Belgium, 7%; and Republic of Korea, 6%. Six countries received about 74% of the total U.S. exports of industrial stones. The countries and the percentage of exports they received were as follows: Belgium, 24%; Ireland, 21%; Canada, 10%; Japan, 9%; France, 8%; and Federal Republic of Germany 6%.

The average annual exports plus reexports of natural and synthetic grit and powder for the past 10 years was 46.0 million carats, with an average value of \$85.9 million. The highest level of exports plus reexports during the past 10 years was 78.8 million carats valued at \$119.3 million in 1991. The lowest was 30.6 million carats valued at \$66.9 million in 1982. The trend of exports plus reexports for the past 10 years was one of continued growth. There was an increase of 158% during the period or an

annual average compounded growth rate of more than 10%.

The average annual exports plus reexports of industrial stones for the past 10 years were 3.0 million carats per year, and the average value was \$31.9 million. The high was 3.6 million carats in 1986, and the low was 1.7 million carats in 1990. There was not a distinct trend for the past 10 years.

The average annual imports of natural diamond grit and powder was 8.0 million carats per year for the past 10 years. The high was 13.0 million in 1988, and the low was 3.3 million in 1982. Imports as measured in carats were about 13% less than those in 1990 and 219% greater than those in 1982. The trend for the quantity of natural grit and powder imported during the past 10 years was one of significant increases. Yet, during this period, the quantity of natural grit and powder decreased from 23% to 20% of total grit and powder imports. During 1991, four countries supplied 78% of U.S. imports of natural grit and powder: Ireland, 34%; Belgium, 20%; the United Kingdom, 14%; and Zaire, 11%. Only Zaire was a producer of natural diamonds.

The average annual imports of synthetic diamond grit and powder was 31.7 million carats per year for the past 10 years. The high was 73.2 million carats in 1990, and the low was 11.0 million carats in 1982. Imports in 1991 were about 19% less than those in 1990 and 440% greater than those in 1982. The trend of synthetic grit and powder imports during the past 10 years was one of continued strong growth until the slight decline in 1989. The average annual compounded growth rate for the 10 years was about 17%; but, the average annual compounded rate of growth from the low in 1982 through 1989 was about 21%. The level of imports in 1988 through 1991 indicated that the growth trend has begun to increase at even a greater rate. Three countries furnished 81% of the synthetic diamond grit and powder imported into the United States in 1991: Ireland, 61%; U.S.S.R., 13%; and Federal Republic of Germany, 7%.

The 10-year average for imports of industrial diamond stones was 7.1 million carats per year, with a high of 11.0 million in 1990 and a low of 3.9 million in 1987. Imports of industrial diamonds lacked a distinct trend during the period; the quantity imported in 1991 was about 63% greater than the quantity imported in 1982. The 1991 imports were about 31% less than 1990 imports, but 1990 imports were highest in the past 10 years. Four countries accounted for about 87% of the diamond stones imported into the United States during 1988: Zaire, 34%; United Kingdom, 22%; Ireland, 20%; and Ghana, 10%.

The United States was a net exporter of diamond grit and powder and a net importer of industrial diamond stones. The United States was a net exporter of industrial diamond based on the total quantity and total gross value. The excess trade balance in industrial diamonds was about 4.2 million carats and \$32.6 million. (See tables 11 and 12.)

World Review

Botswana and the Republic of South Africa were the largest producers of good-quality industrial diamond stones. Australia and Zaire were the world's largest producers of natural industrial diamond and were the primary sources of natural crushing bort as well as substantial producers of industrial stones. Estimates suggest that the U.S.S.R. was the third largest producer of natural industrial diamond, but reliable data were lacking.¹⁹ The next largest, in order of volume, were Botswana and the Republic of South Africa. Other smaller but significant producers were Angola, Brazil, China, Ghana, and Venezuela.²⁰ Total world output of natural industrial diamond in 1991 was approximately 51.8 million carats, a slight increase over that of 1990. (See table 13.)

Angola.—The Government of Angola diamond company, Endiama, entered into a prospecting agreement with a Portuguese-Zairian consortium. The consortium is Sociedade Portuguesa de Envestimentos and SAICAN; both firms

are privately held. It is reported that the Zairian firm may have links with President Mobutu Sese Seko of Zaire. The prospecting rights are along the Cuango River near the Angola-Zaire border, the same area included in the April diamond sales agreement between Angola and De Beers Centenary.

Australia.—Stirling Resources NL has entered into a joint venture with Sabminco NL on Stirling's Boab Creek exploration licence in West Kimberleys of Western Australia. Stirling has identified what is interpreted to be a potential kimberlite pipe and buried alluvial channel. The license is adjacent to Sabminco's Diamond Mountain project area where Sabminco has recovered gem-quality diamonds from drill holes in a buried alluvial channel.

Canada.—Uranerz Exploration, operator of its joint venture with Cameco, announced the recovery of additional diamonds from drill samples from the Fort a la Corne property. The latest stones recovered averaged 0.04 carats, with the largest 0.6 carats. Some of the stones recovered were of gem quality.

Uranerz's exploration program has identified 70 potential kimberlite pipes in a corridor that is 50 kilometers by 20 kilometers from Price Albert to Nipawin in Saskatchewan. The first 15 sites tested proved to be kimberlites and, to date, a total of 160 diamonds have been recovered from drill cores. Uranerz is playing down the exploration results, but experts are speculating on the possibility of a diamond mine in Saskatchewan by the end of the decade. Normally, geologists search for indicator minerals, minerals that form under the same conditions as diamonds, but at the Fort a la Corne property they found the actual diamonds in the drill samples.

Dia Met Minerals Ltd. announced the results of the analysis of one drill hole on the Dia Met and BHP-Utah Mines Point Lake prospect, an 800-square-kilometer joint venture in the North West Territories. Analysis of a 59-kilogram sample of core taken from between 140 and 180 meters yielded 81 diamonds each

less than 2 millimeters in diameter. The drill hole was located in a kimberlite pipe that is estimated to have a surface area of between 40 and 80 acres and to have a depth of 1 kilometer. The Point Lake prospect is about 480 kilometers north of Yellowknife, the capital of North West Territories. The announcement has set off a rush to stake claim around the Point Lake prospect.

Ghana.—The Government of Ghana, Lazare Kaplan of the United States, and Inco Ltd. of Canada have entered into an agreement to mine and market Ghanaian diamonds. This is the first privatization of the diamond industry under the current Government. The agreement was 2 years in the making.

The agreement calls for a two-phased mining plan. First, which will take 7 to 11 years to complete, the mine will be brought to a production level of about 0.5 million carats per year. The second phase will be to bring the mine to a production level of about 1 million carats per year. Currently, the mine production is between 0.1 and 0.2 million carats per year.

Murtob Mining Co. Ltd. of Akwatia purchased a diamond concentrating plant from Somerville Engineering Associates of England. The plant is trommel and jig-grease tables style.

India.—Ashton Mining, an Australian company, negotiated an agreement with the Indian National Mineral Development Corp. to assist in the modernization of the Panna Mine. The mine produced about 20,000 carats of diamonds in 1991, and the modernization intended to increase production by increasing the amount of ore processed.

Indonesia.—Indonesian Diamond Corp. was delayed in the construction of its diamond plant in South-East Kalimantan; the plant was ready for production in December 1991. The pilot plant, capable of running about 30 cubic meters per hour, processed material from the mine until the commercial plant was completed. The delay and cost overruns resulted in the plant costing about \$1.1 million more than the original estimate of

\$2 million. The first diamonds from the commercial operation, 2,200 carats, were sold for an average price of \$191 per carat. It is planned to operate both plants in the coming year to process about 54,000 cubic meters of ore per month and recover about 5,400 carats of diamonds each month.

Japan.—Sumitomo Coal Mining Co. established a new subsidiary, Izumi Diamond, which will be the first Japanese firm to produce synthetic polycrystalline diamonds from graphite for nonabrasive applications. The planned output of the new firm is 1 million carats per year. Japan's Kobe Steel Ltd. announced that its research center in Britain has developed diamond crystals and films for electronic applications.²¹

Namibia.—Consolidated Diamond Mines (CDM) began production at the open pit Elizabeth Bay mine in June. It is planned that the mine will produce about 4 million tons of ore per year that will result in the recovery of about 250,000 carats of diamonds. The production from the Elizabeth Bay mine will increase CDM's annual production to about 1 million carats per year. During the expected 10-year life of the mine, the mine should produce about 2.5 million carats of diamonds.

Monarch Minerals and Mining Inc., a U.S. firm, announced production began at its new diamond mine in southeastern Namibia in July. The mine is on Monarch's 50-square-kilometer mining concession at the mouth of the Fish River.

U.S.S.R.—Reports on Radio Moscow indicate the discovery of a major diamond field in Buryatskaya on the Soviet side of the Mongolian border. It is reported that more than 10 diamond-bearing sites in the eastern part of the Sayany Mountains were found. The discovery comes after 50 years of small-scale prospecting in the region, during which small quantities of diamonds were found.

The world's biggest new source of diamonds in this century may be the five kimberlite diamond pipes near the village

of Pomorie at Lamonsov in the North Russian oblast of Archangelsk. Development plans for the pipes are for two shafts to a depth of about 1,000 meters, one on each side of the pipe. The cost to develop the five pipes, including the infrastructure and power station, is estimated to be \$4 billion. Funds of the project will have to come from foreign sources or joint ventures.

Zimbabwe.—Auridium Consolidated NL of Australia has acquired the exploration license for the Ranch River diamond project that was forfeited by De Beers early in 1991. Kimberlitic Searches Ltd., a De Beers subsidiary, evaluated the project in the early 1980's and found the diamond project was uneconomical at that time. Auridium and its partner, Cornerstone Investments Ltd., believe that, given the current diamond market, the project may be economical during the 1990's. Evaluations will be undertaken to determine if the deposit is economical at this time.

Delta Gold NL of Australia has applied for exploration rights in eight diamond-bearing areas totaling about 4,600 square kilometers. The company already has completed a great deal of fieldwork in the selected areas. (See table 14.)

Current Research.—General Electric announced the production of a new synthetic diamond made almost totally of carbon-13, the heavier and more rare of the two isotopes of carbon. The diamond is more dense and harder than natural diamond or regular synthetic diamond and has greater crystalline perfection. The new diamond's hardness makes it ideal for abrasive and cutting applications and other high-technology uses.

Outlook

Diamond grit and powder should experience substantial increases in domestic demand for every end use during the next 5 years. The increases for synthetic grit and powder are expected to be greater than for natural. The constant-dollar prices of these materials, especially

the synthetic diamond products, should continue to decrease or at least remain constant. This is because planned production increases will make them more cost-effective. The contract construction industry is an area in which the greatest increases will occur. This is because large quantities of saw-grade diamond will be required for highway and bridge repair and replacement. Large increases also are expected in the dimension stone industry as a cutting and polishing media. The stone, clay, and glass industries will increase their uses in cutting, shaping, and polishing media. Additionally, polycrystalline synthetic diamond compacts and shapes will continue to displace natural diamond stone and tungsten carbide drill bits in the mineral services sector. The probable average annual growth rate in U.S. production is about 6%, based on estimates by the U.S. producers. U.S. production of synthetic material is sufficient to supply U.S. diamond grit and powder demand. The United States will continue to be a major exporter.

The major domestic end use for industrial stones in the next 5 years will continue to be in the oil, gas, and mineral industries. These stones are natural and cannot yet be manufactured commercially. Polycrystalline synthetic diamond compacts and shapes have had a major negative impact on the natural industrial diamond stone markets. This will limit the growth of U.S. demand for stone during the next 5 years. U.S. consumption should average between 6 and 7 million carats per year for the next 5 years. Approximately 50% of the potential natural stone applications will be replaced by the synthetic compacts and shapes by the year 2000.

MANUFACTURED ABRASIVES

Manufactured abrasives include fused aluminum oxide, silicon carbide, alumina-zirconia oxide, and metallic shot and grit. Production data for fused aluminum oxide, silicon carbide, and alumina-zirconia oxide were for the United States and Canada. Data for metallic shot and grit were for the United States only.

The fused aluminum oxide, silicon carbide, and metallic abrasives industries continued to undergo consolidation and reorganization during the year. (See tables 15 and 16.)

Fused Aluminum Oxide

Government Programs.—The NDS, as of December 31, 1991, contained 227,152 tons of crude fused aluminum oxide and 46,169 tons of abrasive-grain fused aluminum oxide. The NDS goal for abrasive-grain fused aluminum oxide is 340,000 tons. There is no NDS goal for crude fused aluminum oxide; it is held as an offset against the abrasive-grain goal.

Production.—At yearend, four firms were producing fused aluminum oxide at seven plants in the United States and Canada. General Abrasives, a division of Abrasive Industries Inc. of Clearwater, FL, was purchased by Austrian-owned Treibacher of America. The new name will be General Abrasives Treibacher Inc. (GAT), a wholly owned subsidiary of Treibacher of America, which is a holding company owned by Treibacher Chemische Werke of Austria. GAT operates a plant at Niagara Falls, NY, that manufactures regular and high-purity fused aluminum oxide and a plant at Niagara Falls, Ontario, Canada, that makes regular-grade fused aluminum oxide and silicon carbide. Production of regular-grade fused aluminum oxide in 1991 was 138,440 tons, a decrease of about 16% from that of 1990. The average annual production for the past 10 years was 139,092 tons. The high was 172,157 tons in 1988, and the low was 105,893 tons in 1982. The production trend for the past 10 years was one of sharp decline, 27% in 3 years, followed by up and down years until 1991's production drop to essentially the same as that of 1985. The 1991 production was 24% greater than that of 1982.

Production of high-purity fused aluminum oxide increased 15% to 24,516 tons. The average annual production for the past 10 years was 20,214 tons. The high was 32,634 tons in 1988, and the

low was 13,468 tons in 1982. The production trend for the past 10 years began with production swinging between about 14,000 and 28,000 tons until the major increase of 82% in 1988, followed by 2 years of decline and then the increase in 1991. The period ended with production 182% that of 1982. Total 1991 production of 162,956 tons was 12% less than that of 1990, 37% higher than the low of 119,361 tons in 1982. (See table 17.)

Consumption and Uses.—Fused aluminum oxide has a number of different end uses in the form of graded grain. The total value of sales of fused aluminum oxide-graded grain for all uses decreased 12% compared to that of 1991, and was only 69% of the 10-year high recorded in 1988. Total value of sales by individual end use was all down with the exception of antislip abrasives. Sales for use in bonded abrasives were down 6%; coated abrasives, 17%; refractories, 5%; tumbling media, 22%; blasting abrasives, 19%; polishing cake and buffing compounds, 38%; polishing abrasives, 18%; and all other uses, 27%; and antislip abrasives were up 15%.

Prices.—The Bureau did not collect data on the prices of various grades of fused aluminum oxide. It did collect data on the value of fused aluminum oxide production. The average value of regular-grade fused aluminum oxide, as reported by producers, was approximately \$381 per ton. The average annual value for the past 10 years was \$364 per ton, with a high of \$394 in 1990 and a low of \$324 in 1988. In 1991, the average value of high-purity fused aluminum was \$619, up slightly from that of 1990, still less than the 1989 10-year high at \$635 per ton. The average annual value of the past 10 years was \$560 per ton, with a low of \$476 per ton in 1988. The average value of all grades of fused aluminum oxide in 1991 was \$417 per ton, essentially unchanged from the 10-year high in 1989. The average annual value for the past 10 years was \$387 per ton, with a high of \$420 in 1989 and a low of \$348

in 1988. The trend for fused aluminum oxide values for the past 10 years was a general upward trend from 1981 to 1983, then a general downward trend from 1983 to 1988. The 1989-91 average values increased about 21% compared with that of 1988 and decreased about 2% with that of 1982. Mineral price quotations in various December issues of trade magazines listed prices for regular-grade fused aluminum oxide of \$832 to \$925 per ton, while high-purity was quoted at \$1,110 to \$1,221 per ton.

Foreign Trade.—The quantity of exports plus reexports of fused aluminum oxide decreased 21% to 10,763 tons; the value of exports plus reexports increased 43% to \$25.3 million. The average value of 1 ton of fused aluminum oxide, exported or reexported, increased 82% to \$2,351. During the past 10 years, exports plus reexports have averaged 13,970 tons per year, with an average annual value of \$19.2 million and an average value per ton of \$1,480. The largest quantity of material exported in a single year in the past 10 years was 26,638 tons in 1982, and the smallest amount was 9,915 tons in 1986. During the past 10 years, no trend developed in the export and reexport of fused aluminum oxide. Quantities increased and decreased randomly, and the period ended in 1991 with exports about 60% below those of 1982.

Imports increased about 37% in 1991 to 140,176 tons, and the value of imports increased about 19% from \$66.7 million in 1990 to \$79.4 million in 1991. Average annual imports for the past 10 years were 124,850 tons, with a high of 158,770 tons in 1984 and a low of 98,000 tons in 1989. The trend of fused aluminum oxide imports for the past 10 years was one of general decline throughout 1986, then stabilizing for 3 years at about 81% of the 1981 level. This was followed by a significant 32% decline in 1989 and the 4% and 37% increases in 1990 and 1991, respectively.

World Review.—Union Corp., a Korean company, opened a plant to manufacture

high-purity fused aluminum oxide in Korea. The plant has an annual capacity of about 12,000 tons.

Silicon Carbide

Government Programs.—The NDS, as of December 31, 1991, contained 37,305 tons of silicon carbide; the goal was 26,364 tons. During 1991, the Defense National Stockpile Center of the Defense Logistics Agency disposed of 6,329 tons of silicon carbide. Existing legislation authorizes disposal of 11,158 tons in the future.

Production.—During 1991, four firms produced silicon carbide at six plants in the United States and Canada. At yearend, three firms were operating only four plants, one having closed during the third quarter of the year and another at the end of the third quarter. Production of abrasive-grade material decreased 22% to 42,380 tons from the 10-year high of 54,339 tons in 1990. Average annual production for the past 10 years of abrasive silicon carbide was 45,513 tons, with a low of 36,193 tons in 1983. Production of metallurgical-grade silicon carbide decreased about 27% to 36,562 tons, a 10-year low. Average annual production of metallurgical-grade silicon carbide for the past 10 years was 53,163 tons, with a high of 64,998 tons in 1988 and a low of 36,562 tons in 1991. Total production of silicon carbide decreased 25% in 1991 to 78,943 tons, compared with a 10-year average annual production of 107,151 tons. The high was 123,917 tons in 1984, and the low was 78,943 tons in 1991. The 10-year production trend for all grades of silicon carbide was one of 2 years of stability and then slow growth and recovery through 1989 to 143% of the 1982 production level, followed by the 1990 and 1991 declines. The level of production in 1991 was the lowest since 1955.

Consumption and Uses.—Silicon carbide has a number of different end uses in the form of graded grain. The total value of sales of silicon carbide

graded grain for all uses decreased about 16% in 1991 and was only 68% of the 10-year high recorded in 1988. The total value of sales by individual end use was a mixture of increases and decreases. Sales for use in bonded abrasives were up 4%, coated abrasives were up 9%, refractories increased slightly, tumbling media increased 43%, blasting abrasive decreased 28%, wiresawing abrasives were down 15%, polishing cake and buffing compounds were up 39%, antislip abrasives were up slightly, polishing abrasives were up 11%, metallurgical was down 35%, and all other uses were up 36%.

Prices.—The Bureau did not collect price data on the various grades of silicon carbide. Data were available on the value of production of the various grades. The average value per ton of abrasive-grade silicon carbide, as reported by producers, was \$517, metallurgical-grade averaged \$481, and the average value of all grades was \$500. The average value per ton of abrasive-grade material for the past 10 years was \$506, with a high of \$626 in 1982 and a low of \$436 in 1985. Metallurgical-grade silicon carbide averaged \$438, with a high of \$466 in 1983 and a low of \$391 in 1988. For all grades the average was \$470, with a high of \$535 in 1982 and a low of \$417 in 1985. The trend for the value of all grades of silicon carbide for the past 10 years was one of increase, a general decrease through 1985, then stabilization with 3 years essentially unchanged at 88% of the 1981 value. Then 1989 saw a significant increase of 13% compared with the average value of the past 3 years; 1990 and 1991 both were only slightly higher than the year proceeding them. Mineral price quotations in various December issues of trade magazines listed prices for metallurgical grades of silicon carbide of \$1,110 to \$1,388 per ton, while abrasive grade was quoted at \$1,573 to \$1,758 per ton.

Foreign Trade.—Exports plus reexports of silicon carbide in 1991 were 10,138 tons, a 24% increase compared with that

of 1990. While the total value of silicon carbide exported plus reexported increased only slightly, the value per ton decreased 16% to \$1,065, a 10-year low, and was only 57% of the 10-year high of \$1,865 in 1986. The average annual exports plus reexports for the past 10 years were 6,169 tons, with a high of 10,138 tons in 1991 and a low of 3,859 tons in 1986. The average annual value per ton of exports plus reexports for the past 10 years was \$1,454, with a high of \$1,865 in 1986 and a low of \$1,065 in 1991. The value of exports plus reexports fluctuated greatly during the past 10 years; values were up as much as 75% of the value at the beginning of the period and closed the period 20% less than at the beginning.

Imports of silicon carbide in 1991 decreased 8% in quantity to 69,891 tons, 14% in total value to \$45.3 million, and 7% in average value per ton to \$648. The average annual imports for the past 10 years were 76,244 tons, with a high of 101,600 tons in 1988 and a low of 56,250 tons in 1985. The average value per ton for the period was \$607, with a high of \$694 in 1990 and a low of \$539 in 1986. The trend of silicon carbide imports for the past 10 years was one that generally decreased to a low in 1985, followed by continuing increases until 1988, followed by continuing decreases until 1991 imports were 15% greater than those of 1982. (See tables 18 and 19.)

Alumina-Zirconia Oxide

One firm produced fused alumina-zirconia oxide in two plants, one each in the United States and Canada. Abrasive applications accounted for all of the production. Publishing production data would disclose company proprietary data. Export and import data were not available.

Metallic Abrasives

Production.—Eight firms produced metallic abrasives in nine plants at the end of 1991. During the year, one firm closed two plants and went out of business. The quantity and value of steel

shot and grit produced decreased about 10% and 8%, respectively. The average value per ton was \$394, a slight increase compared with that of 1990. The average annual production for the past 10 years was 178,617 tons, with a high of 213,879 tons in 1990 and a low of 135,843 tons in 1982. The average value per ton during the period was \$363, with a high of \$402 in 1982 and a low at \$310 in 1987. The trend of steel shot and grit production for the past 10 years was one of general growth until the 1991 decline. The 1991 production was equal to about 141% the 1982 production level. Michigan, Ohio, Pennsylvania, Virginia, and Indiana, in decreasing order of quantity, supplied the production of steel shot and grit. During 1991, two companies, one each in Indiana and Ohio, produced chilled and annealed iron shot and grit; by yearend, both plants were closed. Additionally, two firms, one in Michigan and one in New York, reported production of cut wire shot. Production of chilled and annealed iron and cut wire shot and grit declined significantly in 1991, 42% in quantity to 5,916 tons and 17% in value to \$5.5 million. The average value per ton increased about 45% to \$934. The average annual production of these types of shot and grit for the past 10 years was 14,980 tons, with a high of 10,770 tons in 1988 and a low of 5,916 tons in 1991. The average value per ton for the past 10 years was \$533, with a high of \$934 in 1991 and a low of \$388 in 1982. (See tables 20 and 21.)

Consumption.—The quantity of steel shot and grit sold or used decreased 4% to 201,170 tons, the total value decreased 5% to \$82.3 million, and the average value per ton decreased slightly to \$409. The average annual quantity of steel shot and grit sold or used for the past 10 years was 179,732 tons. The high was 214,787 tons in 1988, and the low was 133,275 tons in 1982. The trend for sold or used steel shot and grit for the past 10 years was one of fluctuating decreases and increases. The 1991 sold-and-used value was 49% greater than the value in 1982.

The quantity of chilled and annealed iron and cut wire shot and grit sold or

value decreased about 25% to \$5.8 million. The average value per ton decreased 32% to \$507. The average annual quantity of these shot and grit sold or used for the past 10 years was 14,955 tons, with a high of 18,192 tons in 1984 and a low of 9,152 tons in 1985. The trend for the sold-and-used value for the past 10 years was one of large individual increases and decreases. Changes were as much as 50% in 1 year, with the low in 1985. Since then, there was continued growth through 1989, followed by a significant decrease in 1990 and the small increase in 1991. The 1991 number was only 65% of that of 1982.

The estimated apparent domestic consumption of all types of metallic shot and grit decreased slightly in quantity to 196,090 tons, 8% in total value to \$79.7 million, and decreased 5% in average value per ton to \$406. The formula to calculate U.S. estimated apparent consumption is U.S. sold or used plus imports minus exports. The average annual estimated apparent consumption of metallic shot and grit for the past 10 years was 187,806 tons, with a high of 224,216 tons in 1988 and a low of 144,986 in 1982. The average value per ton for the same period was \$405, with a high of \$432 in 1985 and a low of \$375 in 1987. The trend of apparent consumption for the past 10 years was one of rapid increases and declines until 1985. This was followed by general growth until 1988 consumption was 55% greater than that of 1982, but with the declines in 1989, 1990, and 1991 consumption, it was only 35% greater than that of 1982.

Foreign Trade.—U.S. exports of metallic shot and grit increased slightly to 25,790 tons. The total value of exports increased 26% to \$16.3 million, and the average value per ton increased 25% to \$632. The average annual tonnage of metallic shot and grit exports for the past 10 years was 11,800 tons, with a high of 25,790 tons in 1991 and a low of 6,334 tons in 1986. The average value per ton for the past 10 years was \$731, with a high of \$948 in 1987 and a low of \$390 in 1989. The trend for metallic abrasive

exports for the past 10 years was one of general decline from 1982 through 1983, followed by fluctuating increases and decreases. The 1991 exports were 147% greater than those of 1982.

U.S. imports of metallic abrasives increased 25% in quantity to 9,207 tons, increased about 56% in total value to \$7.8 million, and increased 25% in value per ton to \$850. The average annual imports for the past 10 years were 5,010 tons, with a high of 9,207 tons in 1991 and a low of 2,699 tons in 1987. The average value per ton for the period was \$909, with a high of \$965 in 1988 and a low of \$280 in 1984. The trend for the quantity of imports for the past 10 years was one of up-and-down fluctuations resulting in a general decline through 1987, followed by an increase until 1991 imports were about 207% of those of 1982.

The United States was a net exporter of metallic abrasives in 1991, a position it has enjoyed by a significant ratio for the past 10 years with the exception of 1984.

¹All units of measure in this chapter are metric.

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¹⁸General Electric Co., Specialty Materials Department. Stratapax Drill Blanks. Sales Brochure No. SMD31-451, 8 pp.

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²⁰Work cited in footnote 14.

²¹Hawkins, B. Diamonds in China. Dep. Mines and Energy Affairs, Republic of South Africa, No. 1/82. July 1982, 10 pp.

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TABLE 1
SALIENT U.S. ABRASIVES STATISTICS

		1987	1988	1989	1990	1991
Natural abrasives production by producers:						
Tripoli (crude)	metric tons	104,259	99,928	105,230	94,390	88,642
Value	thousands	\$975	\$864	\$2,537	\$3,194	\$3,271
Special silica stone ¹	metric tons	1,378	1,892	898	3,709	2,205
Value	thousands	\$489	\$566	\$147	\$230	\$161
Garnet ²	metric tons	38,353	42,506	42,605	47,009	50,860
Value	thousands	\$4,350	\$4,707	\$4,408	\$6,939	\$7,534
Emery	metric tons	1,764	869	W	W	W
Value	thousands	W	W	W	W	W
Staurolite	metric tons	W	W	W	W	W
Value	thousands	W	W	W	W	W
Manufactured abrasives ^{3,4}	metric tons	462,773	544,899	535,213	514,869	454,572
Value ⁴	thousands	\$167,593	\$209,998	\$227,761	\$218,207	\$195,635
Foreign trade (natural and artificial abrasives):						
Exports (value) ⁵	do.	\$238,522	\$281,633	\$260,363	\$270,928	\$295,742
Reexports (value) ⁵	do.	\$21,192	\$19,302	\$33,771	\$24,545	\$24,209
Imports for consumption (value) ⁵	do.	\$424,640	\$501,707	\$419,084	\$512,766	\$450,880

¹Revised. W Withheld to avoid disclosing company proprietary data.

²Includes grindstones, oilstones, whetstones, and deburring media. Excludes grinding pebbles and tube-mill liners.

³Primary garnet; denotes first marketable product. Includes crude concentrates.

⁴Includes Canadian production of crude silicon carbide and fused aluminum oxide and shipments of metallic abrasives by producers.

⁵Excludes United States and Canadian production and value of aluminum-zirconium oxide.

⁶Bureau of the Census.

TABLE 2
U.S. EXPORTS OF ABRASIVE MATERIALS, BY KIND

(Thousands)

Kind	1990		1991	
	Quantity	Value	Quantity	Value
NATURAL				
Industrial diamond, natural or synthetic, powder or dust	68,716	\$104,153	77,642	\$115,866
Industrial diamond, natural or synthetic, other	448	5,420	1,163	5,721
Natural abrasives, crude	2,258	1,973	1,680	1,730
Natural abrasives, other	10,856	12,430	10,811	15,335
MANUFACTURED				
Artificial corundum (fused aluminum oxide)	13,675	17,746	10,763	25,259
Silicon carbide, crude or in grains	8,179	10,379	10,138	10,812
Grinding and polishing wheels and stones:				
Diamond	759	13,693	688	13,366
Polishing stones, whetstones, oilstones, hones, similar stone	2,778	10,199	1,564	7,231
Wheels and stones, n.e.c.	904	2,042	647	2,110
Abrasive paper and cloth, coated with natural or artificial abrasive materials	13,327	79,996	12,499	82,027
Metallic abrasive; Grit and shot, including wire pellets	25,559	12,898	25,790	16,285
Total	XX	270,929	XX	295,743

XX Not applicable.

Source: Bureau of the Census.

TABLE 3
U.S. REEXPORTS OF ABRASIVE MATERIALS, BY KIND

(Thousands)

Kind	1990		1991		
	Quantity	Value	Quantity	Value	
NATURAL					
Industrial diamond, natural or synthetic, powder or dust	carats	2,325	\$5,347	1,204	\$3,470
Industrial diamond, natural or synthetic, other	do.	1,250	14,700	1,759	16,008
Emery, natural corundum, pumice in blocks	kilograms	27	590	92	388
MANUFACTURED					
Artificial corundum (fused aluminum oxide)	do.	659	1,373	373	791
Silicon carbide, crude or in grains	do.	17	75	12	14
Grinding and polishing wheels and stones:					
Diamond	carats	18	376	50	949
Polishing stones, whetstones, oilstones, hones, similar stone	number	63	159	24	213
Abrasive paper and cloth, coated with natural or artificial abrasive materials	kilograms	592	1,879	365	2,309
Metallic abrasives:					
Short grit, pellets, etc.		90	46	127	67
Total		XX	24,545	XX	24,209

XX Not applicable.

Source: Bureau of the Census.

TABLE 4
**U.S. IMPORTS FOR CONSUMPTION OF (NATURAL AND ARTIFICIAL)
 ABRASIVE MATERIALS, BY KIND**

(Thousands)

Kind	1990		1991		
	Quantity	Value ¹	Quantity	Value ¹	
Silicon carbide, crude	metric tons	66	\$38,342	65	\$32,751
Aluminum oxide, crude	do.	115	52,818	116	48,817
Other crude artificial abrasives	do.	NA	NA	NA	NA
Abrasives, ground grains, pulverized or refined:					
Silicon carbide	do.	9,143	14,232	4,669	12,462
Aluminum oxide	do.	91	48,904	24	30,555
Emery, corundum, flint, garnet, other, including artificial abrasives	do.	17	6,207	11	4,304
Papers, cloths, other materials wholly or partly coated with natural or artificial abrasives					
		21	118,618	19	117,090
Hones, whetstones, oilstones, polishing stones	number	2	2,294	2	1,845
Abrasive wheels and millstones:					
Burrstones manufactured or bound up into millstones	do.	1,132	4,309	1,469	4,367
Solid natural stone wheels	do.	474	1,415	406	1,372
Diamond	do.	702	16,400	679	16,024
Abrasive wheels bonded with resins	do.	6,406	28,159	6,312	28,873
Other		(²)	38,479	(²)	36,147
Grit and shot, including wire pellets	number	7,346	4,982	9,207	7,820
Diamond, natural and synthetic:					
Natural industrial diamond stones	do.	8,568	40,426	5,341	31,298
Miners' diamond	do.	2,472	32,059	2,255	19,259
Powder and dust, synthetic	do.	73,150	51,976	59,382	43,235
Powder and dust, natural	do.	12,292	13,146	10,606	14,661
Total		XX	512,766	XX	450,880

NA Not available. XX Not applicable.

¹Customs values.

²Quantity not reported.

Source: Bureau of the Census.

TABLE 5
PROCESSED TRIPOLI¹ SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

Use		1987	1988	1989	1990	1991
Abrasives	metric tons	6,637	26,360	26,192	24,090	21,239
Value	thousands	\$3,089	\$3,151	\$3,172	\$3,083	\$3,382
Filler	metric tons	71,160	68,618	63,080	56,468	52,334
Value	thousands	\$9,855	\$9,876	\$9,185	\$11,041	\$10,009
Total ²	metric tons	97,796	94,978	89,272	80,558	73,575
Total value	thousands	\$12,944	\$13,027	\$12,357	\$14,124	\$13,391

¹Includes amorphous silica and Pennsylvania rottenstone.

²Data may not add to totals shown because of independent rounding.

TABLE 6
SPECIAL SILICA STONE
FINISHED PRODUCTS SOLD
OR USED BY PRODUCERS
IN THE UNITED STATES¹

Year	Quantity (metric tons)	Value (thousands)
1987	598	\$7,367
1988	371	5,415
1989	377	5,459
1990	450	6,328
1991	272	3,600

¹Includes grindstones, oilstones, and whetstones. Excludes grinding pebbles, tube-mill liners, and deburring media.

**TABLE 7
PRODUCERS OF SPECIAL SILICA STONE PRODUCTS IN 1991**

Company and location	Type of operation	Product
Arkansas Abrasives Co.:		
Hot Springs, AR	Stone cutting and finishing	Whetstones and oilstones.
Do.	Quarry	Crude novaculite.
Buffalo Stone Corp.:		
Hot Springs, AR	Tumbling and sizing novaculite	Metal finishing media and deburring media.
Cleveland Quarries Co.:		
Amherst, OH	Stone cutting and finishing	Grindstones.
Do.	Quarry	Crude silica stone.
Dans Whetstone Cutting Co., Inc.:		
Royal, AR	Stone cutting and finishing	Whetstones and oilstones.
Do.	Quarry	Crude novaculite.
B&J Construction:		
Parrin, AR	do.	Do.
Halls Arkansas Oilstones, Inc.:		
Pearcy, AR	Stone cutting and finishing	Whetstones and oilstones.
Hiram A. Smith Whetstone Co., Inc.:		
Hot Springs, AR	do.	Do.
Do.	Quarry	Crude novaculite.
Ed Kramer & Sons:		
Plain, WI	Crushing and sizing	Deburring media.
Do.	Quarry	Crude silica stone.
Norton Co. Oilstones, Norton Pike Div.:		
Hot Springs, AR	do.	Do.
Littleton, NH	Stone cutting and finishing	Whetstones and oilstones.
Pioneer Whetstone Co. (Blue Mountain):		
Hot Springs, AR	do.	Do.
Taylor Made Crafts, Inc.:		
Lake Hamilton, AR	do.	Do.
Wallis Whetstone:		
Malvern, AR	Quarry	Crude novaculite.

**TABLE 8
TYPE OF ARKANSAS STONES**

Trade name	Use
Black Hard Arkansas Stone	Polishing the most perfect edge possible.
Hard Arkansas Stone	Polishing blade to a very fine edge.
Soft Arkansas Stone	General purpose.
Washita Stone	Rapid sharpening.

**TABLE 9
GARNET SOLD OR USED BY
PRODUCERS IN THE UNITED
STATES**

Year	Quantity (metric tons)	Value (thousands)
1987	35,812	\$7,744
1988	41,896	11,144
1989	41,320	9,768
1990	45,935	11,759
1991	48,051	13,044

**TABLE 10
WORLD GARNET ANNUAL
PRODUCTION CAPACITY,¹
DECEMBER 31, 1991**

(Metric tons)

Country	Capacity
North America:	
United States	65,000
Europe:	
Norway	8,000
Turkey	700
U.S.S.R.	2,000
Total	10,700
Asia:	
China	20,000
India	28,000
Sri Lanka	100
Total	48,100
Oceania:	
Australia	25,000
Others	900
World total	149,700

¹Includes capacities of operating plants as well as plants on standby basis.

**TABLE 11
U.S. IMPORTS FOR
CONSUMPTION
OF INDUSTRIAL DIAMOND
(EXCLUDING DIAMOND DIES)**

(Thousand carats and thousand dollars)

Year	Quantity	Value
1987	48,877	95,559
1988	71,147	130,300
1989	70,342	105,295
1990	96,483	137,607
1991	77,583	108,453

Source: Bureau of the Census.

TABLE 13
WORLD INDUSTRIAL DIAMOND ANNUAL PRODUCTION CAPACITY,
DECEMBER 31, 1991

(Carats)

Country	Rated capacity ¹	
	Natural	Synthetic
North America:		
United States	—	100,000,000
South America:		
Brazil	1,250,000	—
Guyana	10,000	—
Venezuela	600,000	—
Total	1,860,000	—
Africa:		
Angola	200,000	—
Botswana	5,000,000	—
Central African Republic	200,000	—
Ghana	750,000	—
Guinea	25,000	—
Liberia	200,000	—
Namibia	100,000	—
Sierra Leone	100,000	10,000
South Africa, Republic of	8,000,000	60,000,000
Tanzania	100,000	—
Zaire	30,000,000	—
Total	44,675,000	60,010,000
Europe:		
Czechoslovakia	—	5,000,000
France	—	4,000,000
Germany	—	5,000,000
Greece	—	1,000,000
Ireland	—	90,000,000
Romania	—	5,000,000
Sweden	—	25,000,000
U.S.S.R.	8,000,000	100,000,000
Yugoslavia	—	5,000,000
Total	8,000,000	240,000,000
Asia:		
China	800,000	80,000,000
India	5,000	—
Indonesia	30,000	—
Japan	—	3,000,000
Korea, Republic of	—	5,000,000
Total	835,000	88,000,000
Australia	25,000,000	—
World total	80,370,000	488,010,000

¹Includes capacity at operating plants as well as plants on standby basis. Rated capacity based on 340-days-per-year effective operation.

TABLE 14
DIAMOND: WORLD PRODUCTION, BY TYPE AND COUNTRY¹

(Thousand carats)

Country	1987			1988				1989			
	Gem ²	Natural industrial	Total	Gem ²	Natural industrial	Total	Synthetic	Gem ²	Natural industrial	Total	Synthetic
Angola ^a	180	10	190	950	50	1,000	—	1,165	80	1,245	—
Australia	13,650	16,683	30,333	17,413	17,413	34,826	—	17,540	17,540	35,080	—
Botswana	9,368	3,840	13,208	10,660	4,569	15,229	—	10,676	4,576	15,252	—
Brazil	300	200	500	353	180	533	—	350	150	500	—
Central African Republic	304	108	412	284	59	343	—	334	81	415	—
China ^a	200	800	1,000	200	800	1,000	15,000	200	800	1,000	15,000
Côte d'Ivoire ⁵	15	6	21	8	3	11	—	9	3	12	—
Czechoslovakia ^a	—	—	—	—	—	—	5,000	—	—	—	5,000
France ^a	—	—	—	—	—	—	4,000	—	—	—	4,000
Ghana ⁶	65	400	465	78	181	259	—	86	201	287	—
Greece ^a	—	—	—	—	—	—	1,000	—	—	—	1,000
Guinea ⁶	163	12	175	136	10	146	—	138	10	148	—
Guyana	2	5	7	1	3	4	—	3	5	8	—
India	16	3	19	11	3	4	—	3	12	15	—
Indonesia ^a	7	22	29	7	22	29	—	7	25	32	—
Ireland ^a	—	—	—	—	—	—	60,000	—	—	—	60,000
Japan ^a	—	—	—	—	—	—	25,000	—	—	—	25,000
Liberia	112	183	295	67	100	167	—	62	93	155	—
Namibia	971	50	1,021	890	48	938	—	910	17	927	—
Romania ^a	—	—	—	—	—	—	5,000	—	—	—	4,500
Sierra Leone ⁵	150	75	225	12	6	18	—	90	39	129	—
South Africa, Republic of:											
Finsch Mine	1,455	2,701	4,156	1,372	2,548	3,920	—	1,613	2,997	4,610	—
Premier Mine	772	1,713	2,485	696	1,543	2,239	—	689	1,526	2,215	—
Other De Beers' properties ⁷	1,427	546	1,973	1,388	531	1,919	—	1,360	520	1,880	—
Other	409	30	439	361	65	426	—	348	63	411	—
Total	4,063	4,990	9,053	3,817	4,687	8,504	55,000	4,010	5,106	9,116	60,000
Swaziland	48	32	80	44	29	73	—	33	22	55	—
Sweden ^a	—	—	—	—	—	—	25,000	—	—	—	25,000
Tanzania	87	37	124	60	26	86	—	53	23	76	—
U.S.S.R. ^a	7,400	7,400	14,800	7,500	7,500	15,000	41,500	7,500	7,500	15,000	41,500
United States	—	—	—	—	—	—	W	—	—	—	W
Venezuela	38	68	106	54	74	128	—	70	185	255	—
Yugoslavia ^a	—	—	—	—	—	—	5,000	—	—	—	5,000
Zaire	3,885	15,540	19,425	2,724	15,439	18,163	—	2,663	15,092	17,755	—
Total	41,024	50,464	91,488	45,269	51,202	96,471	241,500	45,902	51,560	97,462	246,000

See footnotes at end of table.

TABLE 14—Continued
DIAMOND: WORLD PRODUCTION, BY TYPE AND COUNTRY¹

(Thousand carats)

Country	1990				1991 ^a			
	Gem ²	Natural industrial	Total	Synthetic	Gem ²	Natural industrial	Total	Synthetic
Angola ^a	1,215	85	1,300	—	1,215	85	1,300	—
Australia	17,331	17,331	34,662	—	17,978	17,978	35,956	—
Botswana	12,146	5,206	17,352	—	12,000	6,000	18,000	—
Brazil	600	900	1,500	—	600	900	1,500	—
Central African Republic	303	78	381	—	300	70	370	—
China ^a	200	800	1,000	15,000	200	800	1,000	15,000
Côte d'Ivoire ⁵	9	3	12	—	11	4	15	—
Czechoslovakia ^a	—	—	—	5,000	—	—	—	5,000
France ^a	—	—	—	4,000	—	—	—	4,000
Ghana ⁶	191	446	637	—	210	490	700	—
Greece ^a	—	—	—	1,000	—	—	—	1,000
Guinea ⁶	130	5	135	—	85	6	91	—
Guyana	3	5	8	—	3	5	8	—
India	3	12	15	—	3	12	15	—
Indonesia ^a	7	23	30	—	8	24	32	—
Ireland ^a	—	—	—	60,000	—	—	—	60,000
Japan ^a	—	—	—	25,000	—	—	—	30,000
Liberia	40	60	100	—	40	60	100	—
Namibia	745	16	761	—	1,170	24	1,194	—
Romania ^a	—	—	—	4,500	—	—	—	4,500
Sierra Leone ⁵	66	12	78	—	175	68	243	—
South Africa, Republic of:								
Finsch Mine	1,462	2,716	4,178	—	1,500	2,500	4,000	—
Premier Mine	724	1,604	2,328	—	700	1,500	2,200	—
Other De Beers' properties ⁷	1,240	474	1,714	—	1,200	500	1,700	—
Other	400	88	488	—	400	112	512	—
Total	3,826	4,882	8,708	60,000	3,800	4,612	8,412	60,000
Swaziland	25	17	42	—	18	12	30	—
Sweden ^a	—	—	—	25,000	—	—	—	25,000
Tanzania	59	26	85	—	56	24	80	—
U.S.S.R. ^a	7,500	7,500	15,000	41,000	7,500	7,500	15,000	60,000
United States	—	—	—	W	—	—	—	90,000
Venezuela	88	245	333	—	90	250	340	—
Yugoslavia ^a	—	—	—	5,000	—	—	—	5,000
Zaire	2,914	16,513	19,427	—	3,000	17,000	20,000	—
Total	47,401	54,165	101,566	245,500	48,462	55,924	104,386	359,500

^aEstimated. ²Revised. W Withheld to avoid disclosing company proprietary data.

¹Table includes data available through May 19, 1992. Total diamond output (gem plus industrial) for each country actually is reported, except where indicated by a footnote to be estimated. In contrast, the detailed separate production data for gem diamond and industrial diamond are U.S. Bureau of Mines estimates except for Australia (1987), Brazil (1987-90), and Central African Republic (1987-90), for which source publications give details on grade as well as totals. The estimated distribution of total output between gem and industrial diamond is conjectural, and for most countries, is based on the best available data at time of publication.

²Includes near-gem and cheap-gem qualities.

³Includes all synthetic diamond production.

⁴Reported figure.

⁵Figures are estimates based on reported exports and do not include smuggled diamonds.

⁶Figures do not include smuggled artisanal production.

⁷Other De Beers' Group output from the Republic of South Africa includes Kimberley Pool, Koffiefontein Mine, Namaqualand mines, and Venetia mines.

TABLE 15
CRUDE MANUFACTURED ABRASIVES PRODUCED IN THE UNITED STATES AND CANADA, BY KIND

Kind		1987	1988	1989	1990	1991
Silicon carbide ¹	metric tons	113	118	117	105	79
Value	thousands	\$48,790	\$50,559	\$56,430	\$51,336	\$39,500
Aluminum oxide (abrasive grade) ¹	metric tons	151	205	195	185	163
Value	thousands	\$56,393	\$71,325	\$81,785	\$77,758	\$67,958
Aluminum-zirconium oxide	metric tons	W	W	W	W	W
Value	thousands	W	W	W	W	W
Metallic abrasives ²	metric tons	198	222	224	219	213
Value	thousands	\$62,410	\$88,114	\$89,546	\$89,112	\$88,177
Total ³	metric tons	462	545	536	515	455
Total value ³	thousands	\$167,593	\$209,998	\$227,761	\$218,207	\$195,635

W Withheld to avoid disclosing company proprietary data.

¹Figures include material used for refractories and other nonabrasive purposes.

²Shipments for U.S. plants only.

³Excludes U.S. and Canadian production and value of aluminum-zirconium oxide.

TABLE 16
CRUDE ARTIFICIAL ABRASIVES MANUFACTURERS IN 1991

Company	Location	Product
Washington Mills Electro Minerals (Canada) Corp.	Niagara Falls, Ontario, Canada	Fused aluminum oxide (regular).
Washington Mills Electro Minerals (US), Corp.	Niagara Falls, NY	Fused aluminum oxide (high-purity).
The Exolon-Esk Co.	Hennepin, IL	Silicon carbide.
Do.	Thorold, Ontario, Canada	Fused aluminum oxide (regular)
General Abrasives, a division of Abrasive Industries Inc.	Niagara Falls, NY	Fused aluminum oxide (regular and high-purity).
Do.	Niagara Falls, Ontario, Canada	Fused aluminum oxide (regular) and silicon carbide.
Norton Co.	Huntsville, AL	Fused aluminum oxide (high-purity) and aluminum-zirconium oxide.
Do.	Worcester, MA	General abrasive processing.
Do.	Chippawa, Ontario, Canada	Fused aluminum oxide (regular and high-purity) and aluminum-zirconium oxide.
Do.	Shawinigan, Quebec, Canada	Silicon carbide.
Washington Mills Ltd.	Niagara Falls, Ontario, Canada	Fused aluminum oxide (regular).

TABLE 17
WORLD FUSED ALUMINUM
OXIDE ANNUAL PRODUCTION
RATED CAPACITY,¹
DECEMBER 31, 1991

(Metric tons)

Country	Capacity
North America:	
Canada and United States	280,000
South America:	
Brazil	96,162
Europe:	
Austria	58,967
France	45,359
Germany	86,183
Italy	18,144
Spain	13,880
United Kingdom	63,503
Total	286,036
Eastern Europe:	
Hungary, Poland, U.S.S.R., Yugoslavia	325,000
Asia:	
China	210,000
India	4,536
Japan	54,431
Korea	13,000
Total	281,967
Australia	100,000
World total	1,369,165

¹Includes capacities of operating plants as well as plants on standby basis.

TABLE 18
WORLD SILICON CARBIDE
ANNUAL PRODUCTION RATED
CAPACITY,¹ DECEMBER 31, 1991

(Metric tons)

Country	Capacity
North America:	
Canada and United States	98,000
Mexico	25,000
Total	123,000
South America:	
Argentina	6,000
Brazil	42,700
Venezuela	2,000
Total	50,700
Europe:	
France	16,329
Germany	36,287
Italy	36,287
Netherlands	50,001
Norway	73,936
Spain	18,144
Total	230,984
Eastern Europe:	
Czechoslovakia, Poland, U.S.S.R., Yugoslavia	158,757
Asia:	
China	175,000
India	13,608
Japan	86,183
Total	274,791
World total	838,232

¹Includes capacities of operating plants as well as plants on standby basis.

TABLE 19
END USES OF CRUDE SILICON CARBIDE AND ALUMINUM OXIDE (ABRASIVE GRADE)
IN THE UNITED STATES AND CANADA, AS REPORTED BY PRODUCERS

Use	1990			1991		
	Quantity (metric tons)	Value (thousands)	Yearend stocks	Quantity (metric tons)	Value (thousands)	Yearend stocks
SILICON CARBIDE						
Abrasives	54,339	\$27,912	3,261	42,380	\$21,921	2,164
Metallurgical	49,890	22,840	7,196	36,563	17,579	5,400
Refractories and other	1,022	584	371	W	W	—
Total	105,251	51,336	10,828	78,943	39,500	7,564
ALUMINUM OXIDE						
Regular: Abrasives plus refractories	164,096	64,687	8,342	138,440	\$52,783	7,840
High purity	21,383	13,071	1,039	24,516	15,175	1,449
Total	185,479	77,758	9,381	162,956	67,958	9,289

W Withheld to avoid disclosing company proprietary data; included with Metallurgical.

TABLE 20
PRODUCERS¹ OF METALLIC ABRASIVES IN 1991

Company	Location	Product (shot and/or grit)
Abrasive Materials Inc.	Hillsdale, MI	Cut wire, steel.
Chesapeake Specialty Products	Baltimore, MD	Steel.
Durasteel Abrasive Co.	Pittsburgh, PA	Do.
Ervin Industries Inc.	Adrian, MI	Do.
Do.	Butler, PA	Do.
Globe Steel Abrasives Co.	Richland, OH	Do.
Do.	Buckle, PA	Chilled and annealed iron and steel.
Metaltec Steel Abrasives Co. ²	Canton, MI	Do.
National Metal Abrasive Co.	Wadsworth, OH	Do.
Pellets Inc.	Tonawanda, NY	Cut wire.
The Wheelabrator Corp.	Bedford, VA	Steel.

¹Excludes secondary (salvage) producers.

²Plant closed during 1991.

TABLE 21
PRODUCTION, SHIPMENTS, AND ANNUAL CAPACITIES OF METALLIC
ABRASIVES IN THE UNITED STATES, BY PRODUCT¹

Product	Production		Shipments		Annual capacity ² (metric tons)
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	
1990:					
Chilled iron shot and grit	W	W	W	W	W
Annealed iron shot and grit	W	W	W	W	W
Steel shot and grit	213,879	\$82,485	209,095	\$86,568	226,279
Other ³	10,260	6,628	10,485	7,781	XX
Total	224,139	89,113	219,580	94,349	XX
1991:					
Chilled iron shot and grit	W	W	W	W	W
Annealed iron shot and grit	W	W	W	W	W
Steel shot and grit	192,134	75,769	201,170	82,344	240,168
Other ³	5,916	5,527	11,503	5,833	XX
Total	198,050	81,296	212,673	88,177	XX

W Withheld to avoid disclosing company proprietary data; included with "Other." XX Not applicable.

¹Excludes secondary (recycle) producers.

²Total quantity of the various types of metallic abrasives that a plant could have produced during the year, working three 8-hour shifts per day, 7 days per week, allowing for usual interruptions, and assuming adequate fuel, labor, and transportation.

³Includes cut wire, aluminum, stainless steel shot, and items indicated by symbol W.

ADVANCED MATERIALS

By William J. McDonough and Robert D. Brown, Jr.

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Advanced materials are polymers, metals, and ceramics fabricated as intermaterial compounds, alloys, or composites. The resultant components have higher strength-to-density ratios, greater hardness and wear resistance, and one or more superior thermal, electrical, or optical properties, when compared with traditional materials. Advanced materials, the basis for many of today's emerging technologies, offer savings in total energy consumption, improved performance at reasonable cost, and less dependence on imports of strategic and critical mineral resources.

DOMESTIC DATA COVERAGE

Over the past 10 years, the publishers of Ceramic Industry magazine have conducted the only systematic survey of the industry, relying on voluntary reporting sales figures and their own estimates of those of nonreporting companies. The information on advanced ceramics reported here is from the results of the Ceramic Industry surveys of 1990 and 1991. These data were generously provided in advance of publication by Ms. Patricia Janeway, Editor in Chief and Associate Publisher.

Kline & Co., Inc. data are the basis for the reported 1990 and 1991 markets for advanced polymer, metal matrix, and carbon-carbon composites. Data for polymer composites are reported separately in the Bureau's Organic Materials chapter of the 1991 Annual Report. These data were provided by Mr. John M. Quarmlay, Project Manager of Advanced Materials for Kline & Co., Inc.

Some definitions of what constitutes advanced polymer, metal matrix, and carbon-carbon composites are required. For instance, the advanced polymer data include composites that are reinforced with advanced fibers. These fiber types include carbon, aramid, high-strength glass, and other high-performance fibers and are usually incorporated as continuous filaments in composites designed for structural applications. Therefore, by definition, chopped fibers and conventional E-glass (low-strength) fibers are not included.

Metal matrix composites are composed of a continuous metallic phase and a dispersed reinforcing phase. The reinforcements are limited to those materials whose physical form and chemical composition are not deleteriously changed during composite formation. Advanced metallurgical technologies such as exothermic dispersion reinforcement and mechanically alloyed metals fall outside this definition.

Carbon-carbon composites are a family of materials that can be produced from a variety of fibers (pan, pitch, or rayon) and carbon-producing matrix materials. Many types of carbon-carbon materials have been included; however, the more technically important carbon-carbons usually exhibit higher density (1.4 to 2.1 grams per cubic centimeter) and higher thermal conductivity. All composites markets are valued at the fabrication feedstock stage.

The Corporate Technology Directory, "Corp Tech," produced by Corporate Technology Information Services, Inc., Woburn, MA, is the primary source used

for domestic industry structure data in the advanced materials area. The 1992 Corporate Technology Directory is a reference on more than 35,000 U.S. entities that manufacture or develop high-technology products.

BACKGROUND

Advanced materials are critical to any nation's commercial competitiveness as evident today with numerous technologies under development by many industrialized nations, with the North American Community, the Pacific Rim Countries, and the European Community (EC) among the major competitors. Each of these three industrial groups have "Critical Technologies" lists to guide them toward future commercial development. At the top of most lists are (1) communications and information technologies, and (2) the synthesis and processing of electronic and advanced materials.

Products For Trade and Industry

Advanced materials technologies are highly competitive fields throughout the world's industrial commodities. The EC consortia are seriously challenging the United States through EC efforts to cooperatively develop "critical technologies" commencing with market driven R&D through incorporating state-of-the-art flexible manufacturing techniques. Also, the EC is working to unify industrial standards and to remove existing trade barriers throughout Western Europe and the newly democratic countries of Eastern Europe and the

former U.S.S.R. At the same time, the Pacific Rim countries, especially Japan, are challenging the United States with their prototype manufacturing and commercialization of advanced structural alloys, composites, ceramics, and superconductors. In particular, the Japanese challenge is being accomplished mostly through large investments in new factories and updated process technologies, with the latter based on total quality manufacturing concepts. Meanwhile, other developing countries and industrialized nations, such as Australia, Canada, and the Republic of South Africa, recognize the need to move from the status of commodity mineral and materials suppliers to full manufacturing participants in advanced materials technologies.¹

Economic Factors

The current recession has made the United States more aware of manufacturing competitiveness as this nation attempts to sustain the annual revenue values generated by exports.² Adding to the uncertain export revenues as this current recession is growing worldwide are changes in the domestic economy. The beginnings of cuts in the Defense budget, the bailouts in the savings and loan industry, and the huge interest on the national debt contribute to the scarcity of investment money necessary to fuel manufacturing growth.³ The nation or community that commercially emerges "first" from this current economic down cycle will be the one able to manufacture goods of very high quality at a marketable price while allowing a reasonable return on investment.⁴ The U.S. Government is committed to assisting manufacturing competitiveness, but the paths toward achieving this success are by no means clear. Many feel that a broad-based, progressive technology plan for government, industry, and university interaction is needed,⁵ but as 1991 ends, the actual role of the Federal Government is still being defined owing to the complexity of the economic and political problems inherent in such an undertaking.

Operating Factors

Large companies and the Federal Government use many small contractors, vendors, and consultants to achieve manufacturing or service goals. For example, General Motors Corp. uses more than 10,000 subcontractors in all its business and manufacturing endeavors. Department of Commerce data report that for the U.S. manufacturing sector, more than one-half of all goods is produced in companies with less than 500 employees. These small companies are limited in obtaining expensive upgrading such as automated machinery, just in time assembly, total quality management, etc. Besides, these original equipment manufacturers (OEM's) must compete, sometimes on a yearly basis, for contracts to continue or follow up with an already existing series of parts or assemblies. Often, both large corporations and governmental operations run on an annual fiscal year funding. For many contractors, there is no guarantee of additional funding, etc. All these factors and many more not mentioned contribute in keeping small U.S. manufacturing companies operating below maximum return on investment. Hence they are very susceptible when competing against the more modern manufacturing practices used by large and small foreign companies with or without assistance from their national Government.⁶

A small business situation exists in Japan where small companies (less than 300 employees) numbering more than 800,000 produce 60% of the goods and for the most part use new manufacturing technologies and other aids to maximize return on investment.⁷ The Japanese small manufacturers operate under a business climate of longer term contracts, and a nonserial, line management style of business planning; e.g., quality circles, and government-operated technical assistance centers. The longer term contracts have an obvious cost and quality payoff for both the OEM companies and the large assembler corporations. Furthermore, the Japanese operate more than 170 public assisted centers, called Kohsetsushi centers, that extend research

services, technical assistance, training, testing, and guidance to small companies. These Kohsetsushi centers initially started in the 1920's.

The EC was quick to copy the success of the Japanese economy and has expanded or set up more industry driven manufacturing service centers; for example, the thirteen centers of the Max Plank Institute in Germany.

Industry Structure

This chapter covers four broad-based technologies that make up the bulk of U.S. advanced materials manufacturing: advanced ceramics, advanced polymer composites, metal matrix composites, and carbon-carbon composites. The industry structure for the first three technologies is similar in their involvement of both large and small manufacturers. The carbon-carbon industry resulted from fabrication facilities established within large aerospace corporations that were initially primarily supported by the Federal Government for defense applications. The carbon-carbon industry structure will be discussed separately from the other three technologies.

The former three broad-based technologies grew from company internal R&D (IRAD), and once a technology was ready for commercialization, the fabrication was contracted out to smaller job companies or specific divisions of large companies. For example, advanced polymer composites companies include a few very large companies, but there are many small companies involved in the actual manufacture of the components. The Suppliers of Advanced Composites Materials Association (SACMA), with 30 members, reports that 90% of the world's production in 1990 was by its members: 12 in the United States, 10 in the EC, and a few in Japan. In the same timeframe, the Polymer Composites Institute listed approximately 450 members. Many of the small companies are subcontractors to the large companies. Today, many of these small companies are entrepreneurial companies, founded by engineers or scientists, and initially started with assistance from government

funding such as the Federal Government's Small Business Innovative Research Program (SBIR), which competitively awards funds to small companies.

Another example of a large company-small company interface occurs in the aircraft powerplant business. General Electric and Pratt and Whitney turbine engine divisions' R&D have led to the development of new heat-resistant metal alloy technologies. The actual fabrication of these new alloys into engine components is contracted out to smaller companies. To optimize the fabrication and quality testing, the turbine engine companies either set their own strict engineering specifications or work jointly with the smaller companies to optimize all technical specifications. As a second example, this same practice is followed by the American Telephone and Telegraph (AT&T) group in developing ceramic substrate technology. Once the process variables are controlled and the quality of a pilot line maximized in their research, development, and engineering laboratory, AT&T subcontracts the fabrication of the substrates to its engineered specifications to smaller companies.

In contrast to the aircraft powerplant business, the methodology of large company manufacturing components internally exists in advanced polymer composites. Recently, two large companies, Dupont Plastics and General Electric Plastics, built large processing plants in the metropolitan Detroit area to supply outer body panels and structural body panels for the automobile industry.⁸ Besides the plant costs, large development costs were necessary to fabricate these composite panels with quality, reproducibility, low cost, and in a timely manner. Advanced polymer processing has historically not been as time efficient a process as the metal fabrication with which it competes, and many production problems were solved. The use of polymer composite body panels was demonstrated on General Motors Corp. All Purpose Vehicles in 1989.

The existence of carbon-carbon composites is related to the Department of Defense's interest in faster and lighter as descriptive adjectives for its aircraft, tanks, ships, etc. The national laboratories, including National Aeronautics and Space Administration (NASA) facilities, and industry—assisted by Federal Government funding—collectively developed these composites to technical and engineering maturity. Carbon-carbon composites are still very expensive to fabricate; many reimpregnations with liquid matrix and refiring at high temperatures must be carried out on very expensive carbon fibers to produce reliable composites. Still, these composites have been successfully tested on combat and support aircraft for the military plus numerous applications for aerospace utilization.

The companies manufacturing carbon-carbon composites are usually spinoff or licensee companies from the large aerospace and aircraft assemblers. U.S. companies such as LTV, Kaiser Aerospace, and today, divisions of various large chemical companies, are all key players in the commercialization of carbon-carbon composites. Many small licensee companies exist today to supply finished components to the military aerospace industries, and the future of these companies and indeed, the future of carbon-carbon composites, are, for the near future, tied to the ongoing downsizing of the Department of Defense (owing to the ending of the cold war).

In summary, the advanced materials industry structure of the four broad-based technologies is a mixture of a few large companies (usually under 10 in number) along with many smaller companies that supply the actual components. The smaller companies range in technical capability from entrepreneurial/high-tech to OEM subcontractors with good technical skills, reliable component fabrication records, and a history of reasonable component costs to the large assembler company. The revenue mix of small companies versus large companies will be partially delineated in the individual subsections of this chapter.

ANNUAL REVIEW

The importance of advanced materials to the U.S. economy has been emphasized this year through increased activities: in Federal and State government participation, in industry awareness, and in university pronouncements. The Federal Government completed the establishment of presidential councils targeting advanced materials. It identified critical technologies for three groups: defense oriented, commercially driven, and scientifically defined. State governments increased their activities to create technology synergism among local industry, university, and state resources.

The industrial sector created more joint ventures with itself, Federal laboratories, and university consortia as well as international collaborations—all aimed at improving their competitive positions in the global marketplace.

The university sector, with funding assistance from various government agencies, continued to broaden R&D areas to include all aspects of manufacturing while graduating students skilled in solving and implementing advanced manufacturing techniques, especially as applied to manufacturing with advanced materials. The use of advanced materials and their complex processing to produce commercially marketable products are keys to the U.S. business success.

The following sections on the government programs highlight the increased interest by the Federal Government in assisting and technically facilitating the modernization of U.S. manufacturing companies to compete in global markets.

Presidential Councils

The Federal Government's role is established with the Office of Science and Technology Policy (OSTP) in the Executive Office of the President. The Director of OSTP, who is the Science Advisor to the President, also chairs the Federal Coordinating Council for Science, Engineering, and Technology

(FCCSET). FCCSET has Assistant Secretary level participation by all agencies having Federal programs involved with critical technologies. Input to both OSTP and FCCSET by industrial, State and local governments, and academia is accomplished through the President's Council of Advisors on Science and Technology (PCAST), again chaired by the Science Advisor. One subset of FCCSET is a Committee on Materials (COMAT), dedicated exclusively to the synthesizing and processing of advanced materials. Both FCCSET and PCAST report directly to the President.

"Critical Technologies" lists came forth from four different U.S. study groups in 1991, each group driven by its own individual missions. The following lists were generated: Defense Critical Technologies by Department of Defense (DOD), Emerging Technologies by the Department of Commerce (DOC), National Critical Technologies by the National Critical Technologies Panel of FCCSET, and the Commercial Airplane and Powerplant Critical Technologies by the Aircraft Industries Association. The three Federal Government lists, in short title form, are shown in table 1. The Aircraft Industries Association (AIA) list is similar in its "short form" headings and describes in detail definitive airframe, powerplant, and aerospace categories as critical technologies to its particular industry. (See table 1.)

All four lists designate similar technology subgroups such as materials, manufacturing, information and communications, biotechnology and life sciences, aeronautics and surface transportation, and energy and environment. Various crosscuts of these four lists, which are used in planning future funding requests, reside in the reports of the National Critical Technologies Panel of FCCSET. Altogether, about 20 technologies are identified as critical with more than 10 technologies categorized in the technical subgroups of materials and/or manufacturing.

During this same time period, the United States placed increasing emphasis

on the importance of critical technologies in the race for global technological leadership. The major outcome of this emphasis was the National Competitiveness Technology Transfer Act of 1989 (Public Law 101-189), which empowered industry, universities, and national laboratories to accelerate the commercialization of new technologies. The law makes provisions allowing national laboratories to enter into cooperative research and development agreements (CRADA's); negotiate licensing agreements for inventions; exchange personnel, services, and equipment with industry and universities; waive rights to inventions and intellectual property; and streamline the processing of agreements.

Department of Defense

Today, the goals and missions of the U.S. Department of Defense are being reassessed with the ending of the cold war and the beginning of democracies and market economies in both the old Warsaw Pact countries of Eastern Europe and the Republics belonging to the "Commonwealth of Independent States." Defense is the largest consumer of U.S. science and technology with efforts funded through the National Laboratories, industrial laboratories, nonprofit research centers, and science and engineering universities. Many legislators regard the breakup of the U.S.S.R. into separate nations coupled with a sluggish U.S. economy as ample reasons to justify reduced Defense expenditures. The Department, however, recognizes the importance of maintaining a level of expertise in critical technologies as necessary to keep the U.S. national defense second to none at a minimum of cost. The use of advanced technology in the Persian Gulf war in 1991, smart bombs, stealth airplanes, and interceptor missiles, led to a rapid conclusion of the hostilities with a minimum loss of U.S. personnel. Besides utility in weapons of war, some of these technologies have "dual use" modes; i.e., a definite defense application plus a marketable commercial/industrial component. The

industrial component is important because it can also be used to increase U.S. gross domestic product through improving our commercial competitiveness.

One example of the Department's critical technologies implementation is the Defense Advanced Research Projects Agency (DARPA) manufacturing "insertion" programs. Because advanced materials are essential components of many new technologies, they are to receive increased attention in the areas of precompetitive engineering, design, and prototyping segments that make up a total manufacturing facility. These DARPA programs are aimed at assisting companies by sharing the cost of developing new manufacturing skills; i.e., flexible manufacturing capabilities and/or total quality manufacturing techniques. These joint manufacturing insertion programs ensure DARPA that the latest state-of-the-art technologies will be available when needed for defense and for the same dollar; the transfer of these newly acquired manufacturing skills to the commercial sector will improve U.S. competitiveness.

Congressional Actions

Congressional bills, introduced in either 1989 or 1990, addressing and/or refining manufacturing competitiveness received funding during 1991. For example, DARPA's Precompetitive Consortia was funded in 1991 as a startup along with the Advanced Battery Consortium and the High Performance Computing Project. The DOC Advanced Technology Program (following in detail) and the National Center for Manufacturing Sciences funds were both increased in 1991 along with the National Science Foundation's Manufacturing Initiatives funds. Also from Congressional bills passed in 1991 will come the Department of Energy's (DOE) National Technology Initiative and the creation of the Critical Technologies Institute. The former will concentrate on increased technology transfer and cooperative research, development, and engineering between the U.S. Government and industry while the latter

will be an executive think tank focusing of facilitating civilian manufacturing and R&D. This Institute will be operated by civilian contractors under the aegis of the National Science Foundation.

Agency Programs

The Federal Government has always supported materials oriented "basic and applied R&D" through its various agencies and departments. The entire effort, loosely coordinated by oversight committees, contains agencies such as NASA, the National Science Foundation, Environmental Protection Agency (EPA), in addition to the Departments of Commerce, Energy, Interior, and Agriculture. Even nonclassified DARPA and Department of Defense projects are included. The 1990 funding level for all these materials-related projects is approximately \$1.5 billion annually, with an additional \$0.3 billion to \$0.4 billion for new facilities construction and equipment costs. In 1991, Cross Cut Strategy Plans were completed to focus and increase the effectiveness of this large multiagency effort in materials-related areas. This coordinated and refocused program was initiated in late 1991 as the Advanced Materials and Processing Program (AMPP).⁹ The AMPP will be coordinated by FCCSET and will contain industrial and university input as part of its planning and feedback mechanisms. Short-term goals are to make the AMPP market driven, improve the science of manufacturing know-how, and plan future R&D projects as national goals (similar in operating objectives to Japan's Ministry of International Trade and Industry). A preliminary Government document outlining the AMPP, released near the end of 1991, contained a chapter entitled "Introduction to the AMPP."

Tables 2, 3, and 4 are summary data from the AMPP showing present and projected funding levels. Table 2, Total AMPP R&D Funding, by Agency, covers fiscal year 1991, fiscal year 1992 (appropriated), and fiscal year 1993 (submitted budget) for the 10 agencies. Table 3 is AMPP R&D Funding, by

Research Component for the same 3 fiscal years covering the following components: (1) synthesis and processing, (2) theory, modeling, and simulation, (3) materials characterization, (4) education and human resources, and (5) national user facilities/other. Table 4 delineates fiscal year 1993 AMPP R&D Funding, by Material Class and Agency. There are 11 "classes" of materials ranging from bimolecular to superconducting, the class identification resulting from the crosscut workshops sponsored by FCCSET. Table 2 clearly shows the Department of Defense AMPP funding decreasing over the 3-year period while the Department of Energy and NASA funding, in particular, are increasing along with various other agencies. An approximate 9% increase overall in AMPP is projected from fiscal year 1991 to fiscal year 1993, assuming the fiscal year 1993 submitted budget is enacted. In the immediate past, Congress has, if anything, slightly increased this type of funding over the amount submitted by the White House Office of Management and Budget. (See tables 2, 3, and 4.)

Another example of U.S. competitive awareness is the Department of Commerce, Office of Technology Administration (DOC-OTA), established in 1989.¹⁰ This office works closely with the President's Science Advisor in coordinating precompetitive manufacturing strategies and programs as a logical followup to AMPP's market driven R&D. The DOC-OTA oversees the Advanced Technology Program (ATP) that focuses on precompetitive engineering, design, and prototyping for manufacturing technologies such as computer-assisted machining and flexible manufacturing. Demonstration facilities exist in various locales countrywide to assist manufacturers and provide incentives for a more rapid modernization of commercial technology in the United States. In 1991, the ATP office awarded, through competitive solicitations, more than \$36 million to various industrial/university consortia and Congress has voted funds for more than \$100 million in awards for 1992.

In addition to competitive awareness, the U.S. Government is responding to the shifting patterns of material use as more advanced materials enter the marketplace. These advanced materials represent an entire spectrum of finished products that did not exist 20 years ago. They range from a single material; e.g., polymer-based liquid containers, to complex composites made from polymer, ceramic, and metal. Examples of the latter are electronic circuit boards and outer-body panels for automobiles. The Government activities carried out by the U.S. Bureau of Mines' Branch of Materials consider material components from their sources of supply, lifecycle analyses, substitutional trends, recycling rates, and on through discards to the environment. This information is focused and summarized in the multi-volume series—The New Materials Society.¹¹ This Branch of Materials is the focal point for data gathering and analysis of overall raw and processed materials flows in our society and is specifically responsible for the collection and interpretation of data on the nonfuel use of organic materials, commodity ceramics, and advanced materials.

Industrial Production

The revenue created by U.S. manufacturing has been decreasing approximately 1% per year over the past 15 years, but over the past 3 years the adjusted annual revenue appears to be leveling out.¹² One reason for this revenue leveling is that U.S. companies are staying competitive, whenever possible, by investing in new equipment for design, engineering, prototyping, and manufacturing. They are using techniques such as computer aided design, computer aided engineering, stereolithography for prototyping, and employing "just in time," "design to assemble," and "total quality" concepts coupled to flexible manufacturing facilities.¹³

At the same time, the U.S. industry in 1991 continued the trend of making ventures and partnerships with foreign companies by jointly developing new

technology, especially technology requiring advanced manufacturing processes.¹⁴ In addition, the outright purchase of U.S.-based high-technology companies by foreign enterprises continued. For example, the top three U.S. companies involved in advanced ceramics (in sales and in R&D) are now foreign owned, with the Norton Co. sale being finalized in 1991.¹⁵ Also, more U.S. companies manufacture "offshore" to remain product cost competitive globally. One of the key reasons for these observed business trends is the large amount of investment capital necessary to develop advanced technology once an R&D idea is proven in the prototype stage. To bring these U.S.-derived R&D technologies to the marketplace at a competitive price requires multiple client partnerships in today's global economy.

World Review

The methodology of presenting data for this document has changed in the past 2 years because the world markets themselves are changing; the advanced materials marketplace is becoming more global as to both customers and suppliers. The international flavor of corporations has evolved to the point that these corporations are now "multinational." This definition causes data gatherers to concentrate on multinational companies with the hope that the data these corporations release contain revenue breakdowns according to country of origin. For instance, Ceramic Age magazine, which supplies this document with advanced ceramic materials data, changed over its sales and marketing questionnaire to reflect the uncertainty of country of origin for manufacturing the products in question. This document reflects these global trends by presenting data showing domestic coverage and world coverage for either revenue or weight of product produced and/or delivered.

For instance, table 5 shows domestic data coverage for 1990 and 1991 for the four technologies covered in this document while table 6 shows world data

coverage for the same parameters. In table 6, the worldwide revenue increase in advanced ceramics is in contrast to the worldwide revenue decrease in metal matrix composites, and carbon-carbon composites. These decreases may be explained: the U.S. military and its allies are the consumers for more than 80% of these three advanced materials technologies. Therefore, the slight decrease in revenues reflects the end of the cold war. The worldwide advanced ceramics revenue increase, at 9%, may be the best estimate of growth—discounting the effects of the end of the cold war. Since the advanced ceramics sector obtains 80% of its revenue from electronic components, the 9% reflects the increasing worldwide markets for communications and computer equipment (see U.S. DOC - 1991 Industrial Output). Also, the very slight increase in worldwide and domestic revenues for advanced polymers (1991 versus 1990) is reflecting the continued use of high-technology, high-cost structures in commercial aircraft applications and in specialty components for the automotive industry. (See tables 5 and 6.)

The projections of world markets for advanced materials (not included in this document) as projected in either sales revenue or tonnage of product sold have undergone drastic downward revisions. These downward revisions are the result of both technical and economic changes occurring in the world. For instance, technically "user friendly" advanced materials were projected to be economically available today based on R&D knowledge of 5 to 10 years ago. Even 5 years ago, positive incremental changes in the way some advanced materials yielded to processing innovations in the pilot plant stage led to under estimation of the technical problems involved in composites overall. The difficulty in assembling matrix materials and property enhancing reinforcements into large-volume, low-cost finished products was severely underestimated when the composites were in the R&D laboratories. Today, the process in making advanced materials

user friendly is occurring but not at the pace projected 5 to 10 years ago. On the economic side, changes brought about by the demise of the U.S.S.R. and other fiscal and economical factors caused recessionary times in 1991 for the United States, the EC, and the Pacific Rim countries. Unemployment in 1991 was running as high as 7% in the EC and 4% to 6% in the United States. These economic factors have caused market revenues for advanced materials to remain level or to decrease slightly. Downward trends can be expected to continue into the 1992-94 timeframe. Information obtained from the open literature indicates that feasibility and pilot plant studies for the commercialization of products using advanced materials are continuing. The ability to manufacture new products or retrofit an existing product to reduce its manufacturing costs or to enhance an existing products' consumer performance appeal can usually be accomplished by utilizing new materials; i.e., advanced materials.

OUTLOOK

The world and U.S. domestic outlook for increasing revenues from utilizing advanced materials will continue to be optimistic based on a number of factors. Open literature citations pertaining to the science and engineering aspects of advanced materials are continuing to increase as are the numbers of trade magazines devoted to the technology development of advanced materials. More universities and associate degree colleges list courses pertaining to advanced materials—both processing and manufacturing aspects. As a further example, trade magazine announcements inform us that more and more types of advance polymeric materials and composites are being studied in corporate laboratories and pilot plants of large chemical companies.¹⁶ Also, DOC data indicate that the slowly decreasing U.S. manufacturing revenues (total dollars for all areas) over the past 10 years have not affected chemical companies.¹⁷ These companies have remained competitive in

the marketplace and have indeed increased their revenues from successfully competing in global markets.

Additionally, advanced materials in the form of engineered composites allow the customer cost savings if the new structural component is designed to replace or combine two or three existing components (performance and cost driven). The continuing efforts toward lighter weight automobiles and aircraft, without sacrificing safety, offer new uses for composite materials, especially fiber-reinforced thermoplastic polymers.

The State of California law requiring 40,000 "zero pollution" passenger vehicles registered in the State by the year 1998 translates into urban/suburban electric vehicles. In fact, a European consortium won the initial contract to manage the earlier phases of this electric vehicle project.¹⁸ These vehicles are to be built in California utilizing advanced polymer composites, along with other advanced composites, and many people believe it will be the beginning of a large industry based on lightweight vehicle technologies.

A second technology related to the internal combustion engine and diesel engine is the "automotive ceramic gas turbine engine" program. The DOE and private industry have been funding this project, known under various project names, for more than 20 years. The successful commercialization of the ceramic gas turbine engine is estimated about 10 to 20 years from now. The timetable became shorter in 1988 when the Japanese announced their own country's effort to commercialize ceramic gas turbine engines for both the automobile and the diesel truck.¹⁹

ADVANCED CERAMICS

Background

Definitions, Grades, and Specifications.—Advanced ceramics are relatively new types of high-performance ceramics with significant potential for future economic impact. Advanced ceramics include electronic and electro-optical ceramics as well as structural

ceramics. Advanced ceramics range in component form from single-phase monoliths to complex composites. They differ from traditional ceramics by the nature of their specialized properties such as unique electrical, electronic, optical, or thermal characteristics. In addition, engineered properties such as high-temperature strength, high fracture toughness, and higher resistance to chemical corrosion are designed into advanced ceramic composites. These materials require more expensive, controlled particle size and impurity level powders as starting feedstocks. Additionally, sophisticated fabrication techniques are necessary to optimize their unique engineered physical properties.

Today, the marketplace potential for advanced ceramics has captured the interest and attention of scientists, engineers, and policymakers. This interest results from the current competition between the United States and other industrial nations to develop new commercial applications for advanced ceramics. The attention given advanced ceramics is most pronounced in Japan with their term "fine ceramics" symbolizing high-technology ceramics manufactured from very fine (small) powders of uniform size and shape. The EC is also interested in advanced ceramics. Worldwide, the development of advanced ceramic technologies by large numbers of nonceramic manufacturers, in competition with ceramic oriented companies, is evidence that advanced ceramics are nearing commercialization.

Ceramics are commonly defined as "inorganic, nonmetallic materials processed or consolidated at high temperatures." Traditional ceramics are primarily based on aluminosilicate compositions, more commonly known as clay minerals, such as the kaolin clays used in pottery, brick, and classical porcelain. Traditional ceramics are most often commodity minerals of the Earth with very little chemical alteration of the naturally occurring clays or minerals. On the other hand, advanced, high-technology ceramics include a wide variety of high-purity, single-phase

oxides, nitrides, carbides, borides, and others. Their feedstock powders usually result from chemical reactions designed to yield single-phase powders of high purity. Both cation and anion impurities must be minimized to realize their desired unique physical properties. Combinations of these high-purity materials into chemical compounds or in the form of second-phase additives (particulates, platelets, whiskers, and fibers) result in engineered advanced ceramics. The properties of these inorganic materials enable applications ranging from electronic components to heat- and wear-resistant parts to optical devices. Additional properties range from high-temperature strength to controlled thermal and electrical conductivity to resistance to high-temperature corrosion and erosion. Therefore, depending on the specific application, these materials can be engineered to exhibit optimum mechanical, electrical, electronic, magnetic, and optical properties.

The numbers of chemical compositions and processing variables necessary for high-performance advanced ceramics are quite large because both cations and anion species are involved in the chemical reactions. However, potentially important feedstock materials; i.e., powders, whiskers, and fibers, are often limited both in quantity and quality. The reasons for these limitations are attributed to (1) incomplete understanding of the complex chemical reactions, (2) very expensive scientific methods necessary to produce high-purity, single-phase feedstock materials, and (3) batch "pilot plant size" production runs (limited near-term market demand prevents massive economy of scale). Nevertheless, progress in producing high-purity, uniform, and batch repeatable feedstock materials at low cost is continuing. Advanced ceramic components of proven performance are today in many niche markets. Their entry into massive markets such as automotive engine components is expected in the near future as feedstock and processing costs decrease while performance and reliability characteristics increase.

Some of the more common high-purity powders available are alumina (Al_2O_3), boron carbide (B_4C), silicon carbide (SiC), silicon nitride (Si_3N_4), sialons (solid solutions of silicon nitride and alumina), and various forms of zirconia (ZrO_2). Other feedstock materials such as whiskers and fibers occur as atypical natural growth phenomena, meaning the materials capable of exhibiting this behavior are rare even in nature. Therefore, scientific techniques employed today to grow whiskers and fibers result in small yields, and the products tend to be very expensive. Today, this situation exists in carbon graphite fiber production where 1 kilogram of fibers costs more than \$1,000. Continued R&D on feedstock technologies offers the potential for low-cost powders, second-phase additives, whiskers, and fibers. This statement is based on similar history and feedstock cost reduction efforts such as aluminum and stainless steel in the metals industry and polymeric fibers (yarns) in the chemical industry.

Products for Trade and Industry.—Aluminum oxide (alumina) is traditionally used for a wide variety of ceramic products, including refractory brick, cements, and castable refractories. Higher purity aluminum oxide compositions, 75% to 99% Al_2O_3 , are high-value materials used because of their electrical resistivity for semiconductor and integrated circuit substrates, high-frequency insulators, holders and spacers for printed circuits, and spark plug insulators. Furthermore, the high strength and hardness of aluminum oxide make it suitable for a host of other applications requiring strength, hardness, and wear resistance. The high heat of formation of aluminum oxide gives it excellent chemical resistance to a variety of corrosive materials.

For high-temperature use, aluminum oxide retains about 90% of its mechanical strength up to $1,100^\circ\text{C}$. However, its high thermal expansion coefficient results in poor thermal shock resistance, which can be positively controlled in transformation-toughened aluminum oxide. Additionally, aluminum oxide

fibers are now commercially available. These fibers are spun from solutions of alumina-containing precursors (1% to 3% SiO_2), followed by heat treatment. They are available as woven preforms, papers, and mats and have use temperatures up to 800°C .

Boron carbide (B_4C) is harder than all known materials, other than diamond and cubic boron nitride. It is used mainly as an abrasive, in abrasion-resistant components, and in ceramic armor applications for airplanes and helicopters. Because of its high neutron cross section, boron carbide is used in the nuclear industry as reactor control elements, radiation shields, and control rod moderators.

Silicon carbide (SiC) is used traditionally as an abrasive and as a component of electrical heating elements. More recently, high-purity silicon carbide is used as a super refractory in many forms: as a monolith, as a fiber, or as a deposited coating. For example, high-purity silicon carbide, with less than 1% impurities, is a prime candidate for automotive engine structural applications requiring high strength at high temperatures with good wear resistance. In addition, high-strength silicon carbide fibers are produced by chemical vapor deposition techniques while platelets and whiskers are under development as second-phase reinforcements for ceramic, metal, and polymer composites.

Silicon nitride (Si_3N_4) exhibits corrosion and oxidation resistance over a wide temperature range and retains its high strength up to $1,300^\circ\text{C}$. Silicon nitride is being evaluated for components in gas turbine engines, heat engines, and high-temperature bearings; cutting tools; industrial wear parts; and ceramic armor. Sialons, solid solutions and compounds from oxynitrides of silicon and aluminum, are similar in physical structure and properties to silicon nitride but with slightly lower operating temperatures. While silicon nitride and sialons are still being developed, niche markets uses; e.g., as lubrication-free bearings, rocket nozzles, and gas shrouds for orbital welders, increase their commercialization potential.

Zirconium oxide (ZrO_2), produced from the mineral zircon (ZrSiO_4 , zirconium silicate) or recently from nuclear-grade zirconium metal, exists in three different crystalline forms, depending on temperature. Historically, this most refractory oxide was detrimentally restrained in optimizing its physical properties by the natural presence of low melting silicates or by its polymorphic transformations initiated at various temperatures. These solid-state transformations physically destroy any monolithic component in its natural state by massive spalling of the structure once a transformation temperature is reached. But by increased research on understanding its phase diagrams, scientists recently have learned to toughen zirconium oxide with small amounts of other oxides that are included in the crystal structure during synthesis. By incorporation of several percent of stabilizing oxides, a phenomenon called transformation toughening occurs. The resulting physical properties are enhanced over the naturally occurring zirconium oxide phases and are not degraded at prior transformation temperatures. This improved performance allows these transformation toughened materials to be used in low-temperature applications such as die draw heads, hot-metal scissors, etc., and cutting materials, especially where impact toughness is required. Hammerheads of zirconium oxide have been used to demonstrate that a metalliclike toughness in ceramics is obtainable by applying the principles of engineered materials. Both lower cost feedstocks and processing R&D efforts are underway in a number of countries—aimed at large-volume commercialization of these transformation toughened components.

A host of other advanced ceramic materials are being evaluated for applications that require optimization of electronic properties, mechanical properties, high-temperature properties, and erosion-corrosion properties. After laboratory pilot plant operations, the next steps in their commercialization are reduction in feedstock and processing costs while marketing efforts attempt to

move the components from low-volume to high-volume applications based on improved performance and pertinent total quality manufacturing practices.

Industry Structure.—The largest U.S. producers of advanced ceramics in 1991 were Corning Inc., Corning, NY, \$1,000.4 million; Cooper Industries, Houston, TX, \$456.0 million as Champion Spark Plug Co.; AC Spark Plug Div. of General Motors Corp., \$308.0 million, mostly spark plugs; GTE, Stanford, CT, \$275.3 million; and Allied Signal, Morristown, NJ, \$212.5 million, Autolite Spark Plug Div.

The largest worldwide producers of advanced ceramics in 1991 were Phillips Electronics N V, Netherlands, \$3,226.0 million; Kyocera Corp., Kyoto, Japan, \$2,557.7 million; Murata Manufacturing Co., Kyoto, Japan, \$1,967.1 million; Sumitomo Electric Industries, Osaka, Japan, \$651.0 million; and NGK Insulators, Ltd., Nagoya, Japan, \$600.0 million.

The top 10 worldwide advanced ceramics producers with 1991 sales of more than \$200 million are primarily manufacturers of spark plugs, optical fiber, electronic components, and porcelain insulators. The smaller companies with sales of less than \$50 million are the major producers of advanced structural ceramics. In the United States, many of these are privately held entrepreneurial companies. Many U.S. advanced materials companies, large and small, have changed owners through mergers and acquisitions with and by foreign companies. The Carborundum Co. and the Norton Co. are now divisions of BP America (United Kingdom) and Saint-Gobain (France), respectively. Additionally, large foreign companies such as Kyocera (Japan) and Hoechst (Germany) have set up research laboratories and manufacturing facilities in the United States. For example, Kyocera America Inc. has plants in nine locations within the United States and even more mergers and/or foreign plant startups are reported in trade magazines. Figure 1 shows the number of the largest

U.S. advanced ceramics producers for 1991.

The sales volume ranges shown in figure 1 represent the total sales of all U.S. advanced ceramics companies, including manufacturers of engineered ceramic products. The company data profiles, as depicted in figure 1, are useful in identifying how mature a particular industry is.²⁰ In the case for U.S. advanced ceramics companies, the company ranges of high, medium, and low sales volumes resemble a bell-shaped curve or for this data as a skewed bell-shaped curve. The shape of any bell curve (gaussian distribution in mathematics) allows comments to be drawn about the distribution. As shown in figure 1, a bell-shaped curve skewed toward the high range sales volume is indicative of a mature, more fully developed industry. (See figure 1.)

Technology.—**Solid Freeform Fabrication for Rapid Prototyping.**—The following three examples are emerging technologies that can impact the commercialization of advanced materials by allowing these materials to be prototyped and manufactured with greater technical reliability, product repeatability, and cost effectiveness than currently exists today.²¹ Advanced materials usually enter the marketplace as "niche market" products, and one advanced material may be the basis for four or more products. Because the number of parts per component is small in a niche market, the cost of prototyping is increased in relationship to manufacturing costs. The first successful attempt at rapid and lower cost prototyping is called "stereo lithography." Stereo lithography allows computer aided design, computer aided manufacturing (CAD CAM) designed components to be transformed rapidly from computer output into a geometric prototype in minutes. A photopolymeric liquid in a vat is turned into a point source solid under the controlled intermittent firing of a focused laser energy beam. The rastering and firing of the focused laser energy fashions the CAD CAM drawing into a three-dimensional prototype of any scale

desired. The resulting photopolymeric prototype can then be used to refine the component design and any new changes in the CAD CAM drawing rapidly turned into a new solid prototype. However, in many applications seeking to use rapid prototyping, the resultant photopolymeric materials are not resilient enough.

The next logical outgrowth of stereo lithography is to sinter powders into solid prototypes and thereby allow many more prototype applications. The new technique builds solid prototypes by selective laser sintering of powders. Starting at the bottom or base line, a thin layer of powder is machine spread over the constant area of the fabrication container. The computer-controlled laser beam selectively sinters the powders into the baseline prototype shape (CAD CAM designed), and then the next layer of powder is machine spread over the same constant area of the fabrication container. By repetitive actions, the selected laser sintering and the thin layer powder spreading result in the finished part. Any three-dimensional shape (with holes, cutbacks, channels, etc.) can be prototyped with a high degree of accuracy and repeatability. For example, using wax powder results in lost-wax patterns for investment castings, tools, molds, and short production runs of durable parts. Initially, wax, polycarbonate, and polyvinyl carbonate powders were successfully utilized. Today, nylon and other polymeric powders along with metal and ceramic powders are being investigated to increase the family of powders amenable to selected laser sintering. Preliminary results indicate parts can be produced 60% cheaper and 80% faster than machined prototype parts.

Continued R&D into rapid prototyping using advanced materials is ongoing today. The ability to go from CAD CAM three-dimensional solids generated on a computer to finished prototypes is a manufacturing asset. Also, using prototypes to test, evaluate, and provide feedback to structure-properties analysis programs allows for rapid optimization of the design and engineering aspects of any advanced material component. The total

cost savings and time savings are prime drivers for future applications involving rapid prototyping as many companies seek ways to optimize their return on investment.

Machinable Green State Billet Stock.—Technically, machinable billet stock(s) designed to produce high-quality parts are accomplished in the following manner. The billet stock is held together for the machining stage by polymeric materials. The polymeric material(s) must be removed, after machining, without degrading the chemistry of the ceramic sintering aids. Additionally, removal of the polymeric materials must not compromise the component shrinkage necessary to achieve fully dense ceramic parts. While firing the machined part to remove the polymeric binders, early stage (low-temperature) sintering must occur lest the machined shape sag under the force of gravity or worst case, just fall apart to powder. This technology requires multifunctional ceramic sintering aids (added initially as very fine wet powders designed to coat the matrix powders). The lower temperature sintering aids start to sinter the matrix powders together as the polymer binders decompose (as gases or as char) due to the rising temperature. The final-stage (high-temperature) sintering aids must replace or augment the low-temperature sintering aids without distortion of the part as the still rising temperature approaches the final ceramic sintering temperature. In reality, the ceramic sintering aids and their interactions with each other and the matrix powder(s), all as a function of rising temperature, are complex solid-state reactions being studied today as state-of-the-art science.

These machinable billets, as they become commercially available, will allow small companies interested in developing niche markets an opportunity to pursue these markets without being a fully integrated vertical producer. R&D is continuing in the area of machinable ceramics, and that fact will eventually allow more companies entry-level status to advanced ceramics.

Low-Cost In Situ Composites of Silicon Nitride.—Silicon nitride, a strong ceramic material with good chemical and oxidation resistance at elevated temperature (1,300° C), is the prime candidate material for advanced heat engines. The operation of any heat engine at a "higher temperature" results in improved thermal efficiency. Today, most heat engines employing metals use liquid or gas cooling to prevent meltdown of the metals. This external cooling lowers considerably the thermal efficiency of most metal heat engines and prevents engine designers from developing more thermal efficient heat engines. R&D continues to develop more thermal efficient engines through engineering newer high-temperature materials.

For instance, the DOE's Ceramic Automotive Gas Turbine Program utilizes silicon nitride materials in all critical components, including the turbine rotor. Silicon nitride, like most monolithic ceramics, has low resistance to fracture and must use reinforcements to improve its toughness to acceptable performance levels. R&D of the past 5 years has produced prototype silicon nitride materials reinforced with fibers and whiskers that, at 1,300° C, have both the strength and fracture toughness that mild steel exhibits at room temperature. The silicon nitride composite at 1,300° C has acceptable performance levels. Ongoing tests and evaluations in the ceramic gas turbine program are aiming at a 3,000-hour lifetime. The forementioned material is approaching 1,000 hours in today's tests. Even if this reinforced silicon nitride is technically successful, its costs are very prohibitive in the highly competitive heat engine business of today because it is a composite material.

Advanced ceramic composites require processing under high pressure at temperature to sinter the matrix phase together. The "inert" reinforcements (between 20 to 30 volume percent to optimize toughness) must be completely surrounded by matrix; i.e., no porosity. This can be accomplished by using high-pressure inert gases to squeeze the composite together at high temperature during processing.

The most favorable technical results of silicon nitride composites have lead many researchers to pursue making in situ composites of silicon nitride. Because most materials adhere to a structure-properties-process-performance paradigm, attempts to duplicate composite structure(s) through chemical and selective grain growth techniques have prior histories of success (citations in the technical literature). R&D funds from industry and government agencies to develop in situ composites of silicon nitride have produced preliminary results indicating limited success. Improved strength and fracture toughness data have been reported by tailoring the grain structure through annealing techniques using selective second-phase additions. The premise is: if composite-like microstructure(s) are produced by processing techniques not requiring high pressure at temperature, then low-cost, in situ composites of silicon nitride will rapidly advance the introduction of ceramic components in cost effective gas turbine engines.

Annual Review

Industrial Production.—The companies involved in the worldwide ceramics industry range from ceramics only producers to ceramic divisions within large multinational corporations. Tables 7, 8, 9, and 10 are a compendium of information available for calendar year 1991 (derived from the Ceramic Industry survey) compared with data for 1987, 1988, 1989, and 1990.²¹

Table 7 shows the emphasis change instituted by Ceramic Industry due to the emergence of multinational corporations. The U.S. sales data for subtechnologies of advanced ceramics; e.g., capacitors or substrates, are not available commencing with 1990. However, U.S. sales data for total advanced ceramics for 1990 and 1991 are shown in table 8, [Note a 3% sales increase in U.S. sales for 1991 versus 1990 (table 7) compared with a 12% sales increase in worldwide sales for 1991 versus 1990 (table 8)]. This fourfold differential may be reflecting the current recession in the United States or

show that the worldwide consumption of advanced ceramics is growing more rapidly in Japan and the EC than in the United States. (See tables 7 and 8.)

Table 9 shows a slight decrease in total sales of all U.S. ceramics with increases in advanced ceramics, whitewares, and refractories sales being offset by decreases in glass and porcelain sales. In contrast, table 10 shows worldwide sales increases in all ceramic categories with total worldwide sales increasing 12% for 1991 versus 1990. Comparing table 9 to table 10 indicates the possible effects of the U.S. recession on the total U.S. sales figures. At best, the U.S. sales data in table 9 exhibit a flatness in the U.S. economy, with certain ceramic technologies increasing sales revenues and others decreasing sales revenues for 1991. (See tables 9 and 10.)

Current Research.—Synthesis of New Matrix and Fiber Materials.—The R&D funds available for advanced ceramics technologies for structural, electronic, optical, magnetic, and medical uses are at a high level in the Federal, industrial, and academic sectors. The current recession has seen a slight decrease in industrial R&D funds. However, the Federal Government's Advanced Materials and Processing Program for 1991 reported an overall increase with a shift in emphasis toward nondefense programs.

The 1991 funding for ceramics is \$137.1 million plus an unknown percentage of \$185 million for composites funding. In addition, the DOC Advanced Technology Program (ATP) for R&D on precompetitive engineering, design, and manufacturing was funded at \$36 million this year with \$100 million allocated for 1992. An unknown percentage of the ATP is targeted for ceramic manufacturing depending on the proposals submitted for competitive awards. Summaries of selected technologies requesting R&D funds within advanced ceramics are listed below.

Current research is aimed at developing new matrix materials with improved properties, such as high-

fracture toughness, higher use temperatures, more erosion and corrosion protection, unique physical properties, etc., and low-cost processing for high-quality components. For advanced ceramics, current research is aimed to develop uniform and higher purity feedstock powders, alloy powders with sintering additives deposited on powder surface, and uniform and low-cost powder whisker or powder fiber blends. For colloidal state ceramics, research will target the development of many more low-cost sol gel powders from the solutions precursor routes, including alloys or coprecipitated powders. For advanced ceramic composites, researchers want to develop more homogeneous alloy powders suitable for blending with second-phase reinforcements, low-cost matrix deposition techniques for building matrix fiber preassembly tapes, and more refractory alloys systems for advanced gas turbine engines.

The effectiveness of fibers as reinforcements in any advanced material composites depends on the fiber(s) intrinsic strengths, surface condition(s) (failure is initiated at surface flaws), and the strength of the interfacial bond between the fiber and the matrix. Research efforts directed toward improved fiber reinforcements cover a variety of silica, aluminosilicate, boron, silicon nitride, silicon carbide, carbon, graphite, and organic fibers. Fibers are incorporated into matrix materials to improve the composites structural properties and occasionally to add other properties such as directional thermal conductivity. Research is ongoing to develop new fiber types and at the same time to lower the very high cost of most fibers.

Engineering, Design, and Prototyping.—R&D efforts are expanding into the upstream areas of product processing as international competition indicates total quality management is necessary for all phases of a product's manufacture. The steps of going from laboratory specimen to an acceptable prototype are now being investigated in a scientific fashion. The

use of finite element models for stress calculations coupled to CAD CAM software techniques is being optimized. Rapid prototyping through various techniques results in less time and capital spent on developing a final part for manufacturing. Flexible manufacturing lines allow companies an economy of scale as well as product versatility. Intelligent processing brings total quality management to a manufacturing process. And finally, computer numerically controlled (CNC) machining ensures product repeatability for finish machining and/or other steps in a manufacturing process requiring machining. These areas and many others necessary to bring a high-quality product to a competitive international marketplace are being researched in this country. The U.S. companies that are employing these cost effective and quality providing techniques are enjoying a marketplace advantage in the worldwide economy today. Soon, more U.S. companies will utilize these modern manufacturing techniques as these techniques prove themselves in the marketplace through a higher return on investment.

Nondestructive Evaluation (NDE).—Fiber breakage during fabrication, poor fiber-matrix adherence, and existence of voids and inclusions in advanced ceramic composites are potential causes of failure in service. Under normal conditions, these flaws are not readily detectable by visual inspection.

Adding to the extrinsic processing flaws aforementioned are failure modes caused by advanced ceramics undergoing stress-related formation of microcracks. These microcracks grow under stress and coalesce to cause brittle failure. In a fiber composite, the growth of the matrix microcracks is arrested by the fibers in the microcrack's path. But if the chemical bond between the fiber and the matrix is not optimized, the result is weakening of the fiber-matrix bond, and eventually, fiber breakage and complete brittle failure of the composite. Further mechanisms for brittle failure are caused by environmental conditions. Exposure

to chemical agents, ultraviolet radiation, heat, atomic oxygen (in space), and ionizing radiation, all contribute toward degrading the properties of advanced ceramic materials. Also, the lack of experience in longtime use of advanced ceramic materials contributes to an incomplete understanding of complex failure modes. This lack of understanding is coupled to today's lack of high-quality and fully characterized materials data bases necessary for engineering and designing reliable ceramic composites. Lastly, variability in the final properties and structures from one production run to the next run result from lack of complete understanding of the processing variables.

Inspecting each component prior to incorporation into a finished assembly requires nondestructive evaluation methods. Today, these methods include ultrasonic inspection, infrared thermography, thermographic stress analysis, X-ray tomography, eddy current measurement, acoustic emission measurement, fluorescence spectroscopy, magnetic resonance imaging (MRI), and pulsed nuclear magnetic resonance (a variation of MRI). New nondestructive evaluation methods are being developed both for initial inspection and for periodic inspection of components in use. For initial inspection, research on using X-rays from compact synchrotrons may be able to penetrate up to 6 centimeters of dense ceramic and identify flaws as small as 20 micrometers (typical flaw size that can grow to cause brittle failure). This technique would operate similar to computer aided tomography (CAT scans in medical profession). For in-service monitoring, two methods are presently under development. The first method involves incorporation of pressure sensitive detectors (piezoelectric or light emitters) coupled with wires or optical fibers to transmit data to a computer system. The second method involves sound detectors to receive acoustic emissions from critical stress-bearing regions in the component for transmittal to an analyzing computer (sound is emitted when microcracks grow).

Outlook

The recession in the industrial countries of the Northern Hemisphere makes the economic data reported for 1991 similar in total value to revenue data for 1990. The 1991 revenue highlights appear in niche areas such as modest revenue gains for engineered ceramics, fiber optics, and the category of other electronics. Total revenues for 1991 in advanced ceramics increased 13% over the previous year and are projected to increase 6% to 8% for the next year (Ceramic Age magazine). (See table 6.)

Ceramics and composites R&D funding, two separate classifications under the Government AMPP, increased in 1991. Larger increases in AMPP funds are projected for both 1992 and 1993. In addition, the ATP funding for precompetitive advanced manufacturing contains funds for ceramic processing utilizing intelligent processing techniques. Both of these governmental programs are expected to grow in the funding made available to advanced ceramics because advanced materials are always listed in the top four categories of the Nation's critical technologies lists. Critical technologies are targeted to receive more funding by both Government agencies and industrial R&D. These technologies represent commercial areas (determined by U.S. study groups) best suited to marketplace success in the near future by matching the best of our R&D talents with our rapidly increasing skills in modern manufacturing techniques.

The outlook for next year's advanced ceramic revenues is projected to be either flat or show a slight increase. Funding increases from both the Government and industry sectors for optimizing the techniques of modern manufacturing have been allocated for 1992. The United States appears poised to challenge global competitiveness in the area of advanced materials (ceramics).

POLYMER MATRIX COMPOSITES

Background

Today's composite market is dominated by polymer matrix materials, followed at some distance by metal matrix composites, with ceramic matrix composites just becoming commercialized. Advanced composite systems (ACS), in general, combine the desired characteristics of two or more materials to engineer a new material with a combination of properties not available by traditional methods of manufacture applied to the separate components. Initially developed for the aerospace and defense industries to achieve lighter weight, higher strength, greater toughness, etc., they enhance the efficiency and performance of many technical systems. ACS's are now being applied in the commercial airframe industry and special niche markets such as sports equipment that demand similar properties.

Definitions, Grades, and Specifications.—Polymers are classified as two basic types: thermoplastic and thermoset. Thermosets are those polymers that form by irreversible chemical reaction and consist of strongly cross-linked chains. Thermosets cannot be remelted and reformed but, rather, decompose at elevated temperatures. Because of the cross-linking, thermosets are strong and heat resistant but tend to be brittle. Examples of thermosets are epoxies, phenolics, vinyl esters, polyesters, and urethanes. Thermoplastics are polymers, with less cross-linking, that can be remelted and reformed. They tend to be less brittle (tougher), more flexible, and stronger in the direction along the strongly linked chains than between. Consequently, if the chains are aligned, the polymer is much stronger in one direction than the others.

A polymer composite is a combination of an organic resin and a reinforcing material in the form of fibers in a variety

of patterns and weaves or short fibers, whiskers, or particles. Generally, only composites containing continuous (i.e., relatively long, not short or chopped) fiber reinforcements are considered as advanced polymer composites. The fibers are typically high-strength glass (S-glass), carbon fibers, boron, ceramic, aramid, or other organic fibers.

Engineered polymers can be divided into two classes, polymer commodity materials and advanced polymer materials. Polymer commodity materials are characterized as high-volume, low-cost materials. Advanced polymer materials (AP's) are low-volume, high-cost materials that usually require specialized processing techniques. A composite containing short fibers in a matrix of advanced polymer material could be considered an advanced composite because of its matrix. This combination is of little interest. The continuous or long fiber composite is more important because of the resulting greater improvement in properties. The great bulk of polymer composites consist of short or chopped fibers or particulate incorporated in a "commodity" polymer matrix. These composites are not considered "advanced," but they will be included in this discussion for a complete picture and for comparisons in consumption.

Polymer composites reinforced with continuous fibers are generally referred to as advanced polymer composites (APC's). APC's exhibit excellent strength-to-density ratios, high stiffness, etc., developed from specialized processing techniques that result in properties approaching theoretical maximums attainable from the particular combination of materials used to form the composite. Organic resins used as matrix materials may consist of epoxies, polyimides, polyacrylates, polyesters, or a number of other high-temperature resins. Fibers may be of high-strength glass, carbon, boron, various ceramics such as alumina and silicon carbide, or high-strength organic materials. In general, the most important physical properties of APC's are determined by the properties of the fibers, so a myriad

of polymers, blends, and alloys may be used as matrix materials.

The matrix materials most often used for APC's are the epoxies and the engineering and high-performance thermoplastic polymers. The epoxies presently are used in more than 90% of APC's. Detailed definitions, grades, and specifications for the hundreds of available polymer matrix materials are beyond the scope of this work but can be readily obtained in the *Plastics Encyclopedia*.²² Specifications for the composites themselves (matrix plus reinforcement) are not written as with commodity materials; the specifications are written for each individual application.

The fact that the great majority of advanced polymer matrix composites manufactured today are composed of epoxy reinforced with carbon fiber or high-strength glass fiber is the result, mainly, of two factors. First, when property and performance specifications were written for current aerospace systems, about 15 years ago, epoxies were the only materials sufficiently developed and understood to be used successfully as composite matrix materials. Additionally, epoxy composites are relatively easy to fabricate because the resin-catalyst mixture has low viscosity and is suitable for a variety of prepregging and forming operations. Moreover, epoxies wet reinforcing fibers very effectively, producing a strong bond between them. Epoxies possess the strength, stiffness, corrosion resistance, and high-temperature stability needed for many high-tech applications.

Epoxies have some disadvantages, however. Though strong, they do not have high fracture toughness; i.e., they are brittle and do not resist high impacts. Epoxies are thermosets; they are difficult to recycle because they are formed by irreversible chemical reactions. They do not soften or melt upon heating but decompose instead.

Products for Trade and Industry.—One dominant use of polymer composites is in the area of corrosion-resistant equipment. In this sector,

polymer composites are used for piping, chemical storage and process tanks, pollution control equipment, walkways, platforms, etc. It has become possible to fabricate and field install large custom hoods and ducts for pollution control systems. Their high strength, low density, and relative ease of assembly, as well as resistance to corrosion, has resulted in the replacement of other materials. This was the third largest sector of nine for polymer composites and represented 15% of the total polymer composite market in 1991. Polymer composites in the other sectors involve mostly end uses, rather than industrial applications.

APC's, because of their high cost, have uses most notably in defense, aerospace, and sporting goods where performance benefits outweigh cost considerations. In defense and aerospace they are used in helicopter rotors, blades, and tail assemblies and in weapons systems as rocket motor cases on missiles and space vehicles. They are finding increasing use in secondary aircraft structures such as control surfaces (flaps, rudders, and stabilizers) or fairings (streamlining covers for aerodynamics) and more recently as primary structures such as wing, tail, and fuselage sections. Composites use in McDonnell Douglas aircraft's military planes, for example, has increased from about 2% in the F-15 to 27% on the AV-8B Harrier currently in production.²³ Boeing Co. has teamed with Sikorsky Aircraft to make the new LH helicopters, both with airframes and skins largely constructed of epoxy-carbon composites.

For commercial aircraft, the major manufacturers are planning to increase use of polymer composites in new generation planes. Boeing, for example, plans to increase the composite content of its highly successful 757 line from 3% in 1990 to 24.5% by the year 2000.²⁴

In sporting goods, the desire for better performance regardless of cost has created a market for fiberglass and carbon reinforced polymers in tennis rackets, golf club shafts, skis, sleds, and toboggans; fishing poles; and bicycles.

A particularly interesting aspect of trade in APC's is the use of "prepreg." This is short for "preimpregnated" composite. A prepreg is a combination consisting of a measured amount of polymer (matrix) and fiber (reinforcement) assembled (but not processed completely) to produce tows, fabrics, and tapes for parts producers. These manufacturers then form the composite to the desired shape and cure the resin to complete fabrication of the product. Thus a composites manufacturer has the option of purchasing polymer and fiber or purchasing prepreg and processing it to produce a part. A major portion of composite materials are traded as prepreg. Total prepreg shipments amount to slightly more than the total weight of fiber traded, worldwide.

The industrial market accounts for only about 5% of the use of APC's.²⁵ The primary use here is in tooling. The main purpose of tooling is to provide the contour configuration that a part assumes as it is finally cured. Metals such as aluminum and steel and electroformed nickel are commonly used as tooling materials. But composite tooling has advantages over metal. There is a better match of coefficient of thermal expansion between the composite being made and the tool. Composite tools are easy to prepare by lay up over a plaster mold. Their good heat transfer properties allow increased productivity through more rapid cycling of the process.

Other applications are developing. Robot arms, for example, with less inertial mass than metals, contribute to greater speed and lower systems and energy costs in automated manufacturing.

Industry Structure.—The industry structure in the polymer composite sector is such that the APC materials area is dominated heavily by a few large companies while there are many (and therefore, smaller) companies involved in the actual manufacture of commercial parts from polymer composites. In 1990, more than 90% of the world production of APC material was produced by the members of SACMA, less than 30 companies: about a dozen in the United

States, about 10 in Europe, and a few in Japan. On the other hand, the membership in the Composites Institute, the largest organization inside the Society of Plastics Industries, is at about 450 members. Intermediate in size and number are the companies that manufacture actual parts from APC's and those that produce polymer composite materials. A chart indicating the domestic companies producing APC materials is shown in figure 2. (See figure 2.)

Technology.—Processing.—Most polymer composite processing technologies influence the properties of the finished product, perhaps far more than metals or ceramics, whose properties are somewhat more intrinsic. Various fabrication technologies applicable to PMC's are listed and described briefly in tables 11 and 12.²⁶ These tables also list the predominant type of polymer processed, the form of the polymer prior to processing, and the typical shape of polymer composites made. The exact details of many of the techniques are proprietary.

The most widely used techniques for the fabrication of polymer composites are the open mold methods. The open mold methods include hand lay up or spray up (contact molding), pultrusion, filament winding, continuous laminating, and centrifugal casting. These technologies account for 65% of the polymer matrix composites produced. The closed mold methods include reaction injection molding, high-pressure laminating, and match die (low-pressure) molding. The closed mold methods are used to manufacture 35% of the domestic polymer matrix composite production.

The high-volume methods of hand lay up or spray up (open mold, contact molding) and continuous laminating are used to fabricate 62% of the production of the open mold class or slightly more than 40% of the total polymer matrix composite production. The remaining open mold techniques, filament winding, pultrusion, and centrifugal casting comprise 38% of the open mold production and 25% of the total.

The main closed mold technique is reaction injection molding, accounting for 58% of the closed mold production or 20% of the total. Other closed mold methods include high-pressure laminating and match die (low-pressure) molding, which are used for about 40% of the closed mold production or 14% of the total polymer matrix composites production.²⁷ (See tables 11 and 12.)

It is possible to control properties by varying conditions under which materials are processed. In particular, fibers and films can be made by processes that include close control of polymer chain orientation by drawing under controlled temperatures. Orientation of polymer chains affects strength, stiffness, and elevated temperature properties. For example, polyethylene terephthalate (PET) bottles can now be made under controlled conditions to achieve thermal stability at temperatures up to 88° C. This capability allows the use of PET in the hot-filled food packaging market. The old and new material are still chemically the same, PET. But changes in processing alter the internal structure of the material, resulting in greatly enhanced properties.

Mold design is a very important prefabrication step. The molding process must result in the desired surface appearance, and the mold must be able to withstand corrosiveness of both the material and the process. The process chosen must also match the flow properties of the resin, the geometry of the part, and the mold materials. An example showing the importance of proper processing and mold design is in the manufacture of continuous fiber reinforced thermosets. Because the long fibers in the thermosets are broken up and/or do not flow into the thinner sections, the use of transfer or plunger molding will result in degraded reinforcing fibers and lower strength compared to using compression molding. Furthermore, fibers may flow off into thin, intricate sections of a composite product during compression molding. In such a case, equal properties may be available from a less expensive material that can be injection molded, so it is

important to consider the desired properties of the part, the various materials that can be used to make it, the various mold materials available, and the molding process itself when designing a manufacturing process for a composite.

Joining Methods.—Although the number of component parts required for a system is generally fewer with polymer composites than with metallic systems, particularly in aerospace systems, parts must still be assembled with fasteners or adhesives. If the strength of the joint is less than that of the composite parts, much of the advantage of using the composite part is nullified. Hence, joining methods are receiving a great deal of attention. Improved polymer and metal materials for use as bolts and rivets are being developed, and high-strength adhesives and direct bonding methods are being researched. Perhaps more importantly, new computer-aided design methods have been utilized to predict stress levels within the composite and at the joints of assemblies. This enables engineers and designers to develop structures in which stresses are minimized in critical areas, such as joints.

Applications.—Polymers have been replacing glass, ceramics, metals, and paper in many applications. They are being used in applications from microwave food packaging to sporting goods and satellites. Their special properties have been exploited by design engineers in structural applications. Polymers have many favorable properties and characteristics. In general, they are corrosion resistant, higher in strength-to-density ratios, and usually allow fabrication of a complete assembly using fewer individual parts.

The first application of APC's was in the defense/aerospace industry, beginning in the 1970's. This is still the dominant area of application, with the current shift being from military to civilian aircraft and to the automotive industry in the future. APC's have been used extensively in smaller military aircraft and military and civilian rotorcraft. They are also used in stealth aircraft and the

Beech Starship. These advanced composites have superior strength-to-weight ratios and stiffness compared to the metals they replace in these applications. Resulting weight savings range from 10% to 60% over metallic designs, with a 30% saving being typical. Weight savings can be used to increase payload capacity, speed and maneuverability, and/or to reduce fuel consumption. The high value of weight reduction makes advanced aircraft the ideal market for these new materials. Because of its polymeric matrix, these composites have superior vibration-damping properties and resistance to fatigue and corrosion compared to metals.

The automotive industry becomes a more likely candidate for greatly increased use of APC's as regulations and consumer desire call for lighter cars. So far most applications of polymer composites have been in body panels, usually through the use of sheet molding compound (SMC). The Pontiac Fiero had an all-composite exterior. Composites have also found applications in automobile structural parts, in drive shafts and leaf springs. The roof and liftgate of the 1992 General Motors Saturn are made from SMC. Later models of the Camaro and Firebird will have composite body panels.²⁸

The latest American high-performance sports car, the Dodge Viper, will have glass-reinforced acrylic body panels. It will be Chrysler's first composite intensive vehicle.²⁹ APC's have also found applications in sporting goods, robotics, and medical devices.

Recycling.—Although relatively low recycling rates have been considered a problem for polymers in general (with about 60% of current production going to landfills annually) and with composites in particular, it is encouraging to note a high level of attention to finding solutions.³⁰ The number of composite industry executives who feel that recyclability is very important has risen steadily from 25% in 1988 to 55% in 1991.³¹

R&D engineers have begun to consider the desirability and feasibility of recycling in the early designs of new materials and

products. Some polymer composites are already being recycled in significant amounts. Azdel, a long, continuous glass-reinforced polypropylene composite produced by a joint-venture corporation formed through cooperation between the General Electric Co. and PPG Industries, Inc. is a good example. In tests to show recyclability, Azdel parts containing 40% glass fiber reinforcements were reheated and formed by compression molding five times, with property tests after each refabrication. There was no loss in tensile or flexural strength and only a minimal loss in toughness.³²

Ground sheet molding compound (containing fiberglass reinforcements) from Fiat body parts has been added to polypropylene along with a Union Carbide reinforcement promotion system of organosilicon chemicals. The resulting new composite did not completely match the properties of a similar composite made from polypropylene and virgin fiberglass, but the properties obtained make the recycled material worthy of consideration for applications.³³

For APC's, the main recycling problem is how to separate the fibers from the resin and reuse them economically. Recycling APC scrap may become economically feasible because of the high cost of carbon fibers. The matrix materials currently used are predominantly epoxy resins. Therefore, much of the research conducted has been for the recycling of this type of composite matrix.³⁴ In the uncured condition, epoxies are soluble in organic solvents such as acetone or methyl ethyl ketone. After the epoxy is dissolved, the recovered carbon fiber can be reused. After curing, however, epoxies are insoluble, so this procedure can only be used for prompt scrap and rejects.³⁵ Fortunately, most scrap consists of prepreg sections so this technique can be readily utilized. Cured epoxies can also be decomposed thermally below 400° C in air or at higher temperatures under an inert gas (to protect the fiber from oxidation), and the fiber may be recovered; the fiber surface, however, is affected so that lower fiber-matrix adhesion is observed in new products.

Fiber breakage may be sufficient to render fibers useful only as discontinuous reinforcement.

Fiber-matrix separation should be easier for the newer thermoplastic matrix APC's. Because the matrix material melts at high temperatures (rather than decomposing), separation is possible even after curing, and both the fibers and the matrix material may be recycled. A composite with a thermoplastic matrix can also be softened or melted and recycled simply by reprocessing while the matrix is fluid to fabricate a new component the same as or different from the original component.

Economic Factors.—The defense and aerospace industries have remained the principal driving forces behind the growth of advanced fiber composites. The next area for expansion will be in commercial transport aircraft.

Currently, the United States is the leader in applications of advanced fiber composites systems, but growing foreign activity is a definite threat to U.S. competitiveness in the commercial airplane industry. In 1990, the U.S. aerospace industry led all U.S. manufacturing sectors by posting a positive trade balance of almost \$30 billion. This decreased to a \$27 billion positive trade balance for 1991, still enough for first place by a wide margin. Figure 3 shows the trade balance in 1991 for various industry sectors.³⁶ (See figure 3.)

Survival in this industry depends on which airplane consortium produces the most reliable, fuel-efficient product. The consortium with advanced composites technologies that have been proven and tested will win the largest orders. Another factor that weakens U.S. competitiveness is the increasing U.S. dependence on foreign suppliers for such raw materials as advanced fibers. Japan and Western Europe are primary suppliers of both high-grade fine ceramic powders and advanced fiber reinforcements for composites; the new Department of Defense requirement for at least one-half of the polyacrylonitrile (PAN) carbon fibers purchased to be

domestically produced will not apply to commercial aircraft manufacturers. This is very important because it is hoped that anticipated Department of Defense budget cuts will be balanced by increases in commercial applications of advanced composites.³⁷

To compete effectively with traditional materials in the aerospace market (metal alloys based on aluminum, steel, and titanium), producers of advanced composites need to aggressively market their new materials. Current material use (by weight) in the Boeing 767 airliner's as follows: 80% aluminum, 14% steel, 2% titanium, and only 4% nonmetallics.

The DOC has reported that the consumption of advanced composites has been growing at a rate of 20% annually with 70% of that growth occurring in the aerospace industry.³⁸

Annual Review

Legislation and Government Programs.—Important governmental decisions may affect the polymers industry within the immediate future. The main factors are the Clean Air Act and the Resource Conservation and Recovery Act. Congress is currently considering the reauthorization of the Resource Conservation and Recovery Act. This will impact heavily on solid waste regulations. This act is ultimately likely to dictate national recycling goals. The 1990 version of the Clean Air Act is likely to require regulation of the polymer industry in general, including the production of composites. In light of these possibilities, a Society of the Plastics Industry task force is reviewing the industry's stand on workable policies regarding resource conservation, pollution abatement, and energy.

The Corporate Average Fuel Economy (CAFE) Act also affects the polymer composite industry. By requiring greater fuel economy in automobiles, this law encourages the use of lightweight polymer composites for body panels and structural components.

Production.—Generally, production has risen to meet increased demand in the polymer composite sector for the past decade, with an average annual growth rate of 5% for the 1980's. The composite growth process was mainly one of substitution for other materials in existing applications. Composite production grew at a rate twice that of the growth in gross domestic product (GDP) from 1983 to 1988.³⁹ The entire economy, world and domestic, has slowed in recent years, and composite production entered a near-no-growth phase. Production is expected to resume, growing at a rate twice that of the GDP in the 1990's.

The growth in production for APC's has been mostly a process of developing new applications or performing certain high-tech jobs at greater efficiency through lighter, stiffer, stronger, etc., materials. Production growth for this sector has been almost entirely for military and aerospace applications, where high costs were not a great concern. This dependence on military applications brought 20% annual growth rates to some areas but also a large volatility in demand due to current and anticipated cuts in defense acquisitions. Unless costs can be cut and products developed for the civilian consumer sector, the utilization of increased production capacity will only result in oversupply.

Consumption and Uses.—U.S. polymer composite markets can be divided into nine categories: aircraft-aerospace-military, construction, consumer products, appliance-business equipment, corrosion-resistant equipment, electrical-electronic, marine, transportation, and other. Table 13 presents the shipments of these materials by market category for the years 1987-91. Data for this table were compiled by the Society of the Plastics Industry.⁴⁰ (See table 13.)

The U.S. aircraft-aerospace-military market has remained somewhat stagnant during the past few years. After peaking at 41 million pounds in 1989, the 1990

market dropped to 39 million pounds. In 1991, this market was the same. The appliance-business equipment market used 153 million pounds of polymer composites in 1990, but shipments in 1991 dropped more than 12% to the same level as 1985-86, 135 million pounds. The U.S. construction industry did not recover from the recession. In 1990, polymer composite consumption dropped to 468 million pounds, down from 470 million pounds in 1989. Polymer composite use in this sector dropped further to 420 million pounds in 1991. These figures are significantly down from the previous highs in 1987 and 1988.

The U.S. consumer products market stood at 165 million pounds in 1990. Shipments decreased by 10% in 1991 to 149 million pounds. In 1990, the U.S. corrosion-resistant market stood at 350 million pounds. A modest rise was seen in 1991 to 355 million pounds. Polymer composites struggled to maintain position, but this was mainly due to general economic conditions rather than a reversal of the trend for composites to replace other materials in places where corrosion resistance, high strength, and ease of assembly are required.

Shipments to the electrical-electronic market reached 241 million pounds in 1990. A small decrease (less than 1%) was seen in 1991, with shipments falling to 231 million pounds. The popularity of fiberglass boats over the past decade made the marine market the fastest growing user of polymer composites at that time. The economic slump left retailers with excess inventories, resulting in a market decline starting in 1989. Continued high retail inventory caused the 1990 market to shrink even further. Composite purchases for the boating industry continued to decline in 1991 and dropped from 375 million pounds to 275 million pounds. In 1990, U.S. polymer composite use within the transportation market stood at 705 million pounds. In 1991, use decreased slightly to 682 million pounds.

Other products using polymer composites include medical equipment, orthopedic appliances, and dental materials. In 1990, consumption totaled

79 million pounds. This market decreased to 74 million pounds in 1991.

Kline & Co.'s estimated 1991 U.S. market for 17.1 million pounds of advanced polymer composites is \$2.4 billion or 53% of the world market. This represents no change in value but a decrease of 13.6% in weight from the 1990 amounts. Figure 4 (Kline & Co.) shows the 1991 U.S. market by end-use industry. These data show \$920 million (5.6 million pounds) for aircraft; \$1,080 million (4.1 million pounds) for missiles and space; \$52 million (2.4 million pounds) for armor; \$170 million (2.6 million pounds) for recreational; and \$155 million (2.4 million pounds) for other. An interesting point about figure 4 is that although the data show aircraft applications consuming more than 30% of the U.S. market, missile programs account for the majority of the parts used. The heavy use of advanced composites in these programs helps to explain why there was no change in value produced while there was a drop in how much was consumed. (See figure 4.)

World Review.—The estimated 1991 worldwide value for 31.1 million pounds of APC's is \$4.5 billion for three regions, North America, Western Europe, and the Pacific Rim (figure 5), according to Kline & Co. This represents an increase of 12.5% in value and a decrease of 5.8% in the amount consumed compared with the data for 1990. Again, according to Kline & Co., the estimated 1991 world market for APC's by end-use industry is shown in figure 6, as follows: \$1,450 million (9.4 million pounds) for aircraft; \$1,680 million (6.1 million pounds) for missiles and space; \$420 million (4.6 million pounds) for recreation; \$130 million (3.8 million pounds) for armor; \$35 million (0.6 million pounds) for automotive; and \$695 million (5.6 million pounds) for other. A notable feature in figure 6 is the difference in the missiles and space in terms of weight and dollar values: 20% by weight and almost 40% by cost. Higher costs are attributed to labor-

intensive fabrication and low-volume production. (See figures 5 and 6.)

Current Research.—**New Materials.**—The level of research effort in polymer technologies has shifted in areas of emphasis in recent years, according to Owens Corning's "Trends 1991."⁴¹ The survey of leading executives of the composites industry showed a steady decrease in the companies active in new materials development from 55% in 1988 to 39% in 1991. New applications development showed the quickest increase, from 21% to 32% of the companies polled from 1990 to 1991. This area of effort had dropped from 27% in 1988. R&D on new processing techniques held steady at about 25% of the companies from 1988 to 1991 whereas R&D on improving existing materials and efforts on quality control decreased from just less than 15% to slightly more than 10% for the same time period. Forty-seven percent of the executives expected a decrease in R&D expenditures in 1991. Although 36% expected an increase, this was the lowest level of optimism since the survey started in 1986, representing a 16% drop from that of 1990. All of these dampened expectations are a reflection of the general economic conditions and attempts to keep short-term profits up, quarter by quarter.

Current research to develop new matrix materials is aimed at overcoming the disadvantages of epoxies, such as low-fracture toughness, processing by irreversible reactions, and high viscosity. A number of epoxy blends with greater fracture toughness than single epoxies and lower viscosity than thermoplastics have been formulated and are being evaluated. These materials may find uses in areas demanding improved impact resistance, but they will still be difficult to repair or recycle.

Increased repairability and toughness are the main driving forces for the greater implementation of thermoplastic resins as matrix materials. Polyetheretherketone (PEEK), introduced in 1982, is a leading contender for more applications. Formable by heat and low pressures, it

also has a preprocessing advantage over thermosets (mostly epoxies) in that PEEK prepregs do not require refrigeration for storage and shipment. Thermoplastic processing technologies, being more automated, result in shorter cure and production times, resulting in increased productivity. Newer thermoplastic resins being developed as matrix materials are polyphenylene sulfide (PPS), thermoplastic polyimides, polyarylates, and polyetherimide (PEI).⁴²

Liquid crystal polymers are also being developed as matrix and even stand alone materials. Their internal structure is such that the molecular chains forming the resin become oriented parallel to each other so much that the material becomes "self reinforcing." This results in exceptionally high strengths. These materials can be processed at high temperatures, are thermally stable, and are solvent resistant. They are lower in density than epoxies. While it is expected that they will eventually find implementation in large structural applications, they are likely to be used first in large volumes as injection molded chip carriers in the electronics market.⁴³

New Fibers.—The effectiveness of fibers as reinforcements in APC's depends on their intrinsic strengths, surface condition (failure is initiated at surface flaws), and the strength of the interfacial bond with the matrix. Research directed toward finding improved reinforcements remains intense although development efforts have declined owing to general economic conditions. A variety of silica, aluminosilicate, boron, silicon nitride, silicon carbide, and organic fibers are being researched and evaluated for use as reinforcements for improved composite structural materials. A new high-performance E-glass, Star Stran 748, has been introduced commercially by Schuller International (formerly Manville). This fiber was designed specifically for injection molding, using PPS or PEI as matrix materials.⁴⁴

Nondestructive Evaluation (NDE).—Fiber breakage during

fabrication, poor fiber-matrix adherence, and existence of voids and inclusions in polymer composites are potential causes of failure in service and are not detectable by visual inspection because the flaws are internal. Because composite production methods do not yield 100% products at or above specifications, the only way to ensure complete quality control is to examine each component before the assembly of critical structural parts. Several methods are under development or are being used for this purpose. These include ultrasonic inspection, infrared thermography, thermographic stress analysis, X-ray tomography, eddy current measurement, acoustic emission measurement, fluorescence spectroscopy, magnetic resonance imaging (MRI), and pulsed nuclear magnetic resonance (a variation of MRI).

Because of the lack of experience in longtime use of APC's and the variability of properties resulting from lack of uniformity in processing, much effort is being expended to evaluate new materials for deterioration of properties while in service. Nondestructive evaluation methods are being developed for both periodic inspection of components in use, as well as methods based on continual monitoring during service. Two methods presently under development involve the incorporation of pressure sensitive detectors (piezoelectric or light emitters) into an assembly to detect deformation of a component or sound detectors to receive acoustic emissions from critical points in a component as a way to detect internal changes occurring in the component.

Although perfect adhesion at the fiber-matrix interface is generally thought of as the desirable condition, for certain applications the opposite may be true. For polymer composites used for ballistic armor, poor interfacial adhesion has been found to result in even better ballistic performance. S-2 glass fiber is used for reinforcement in this composite. In most cases, the desired phenomenon is for excellent fiber-matrix adhesion to allow stresses to be transferred from matrix to fibers. But in this application, controlled less-than-perfect adhesion maximizes the dissipation of impact energy because the

loosely bound fibers are able to "give" and absorb and distribute more of the impact energy from a ballistic projectile.⁴⁵ This composite offers the same structural performance and ballistic protection, has better corrosion resistance, and weighs 16% less than aluminum in the same application.⁴⁶ This is a good example of how control (achieved during processing) of structure can result in the improvement in properties desired for a specific application.

Outlook

The outlook for polymer composites is somewhat cloudy, reflecting the general economy. The transportation industry, however, as shown in table 13, is expected to continue to dominate the polymer composite market in the near term. The current recession, which has affected polymer composite shipments since 1988, may continue its negative effect in 1992 shipments. The largest slump is expected in the aerospace sector, which had been holding firm in spite of poor general economic conditions. The largest gain is expected in the construction area, which had slumped badly in 1991. Most sectors are expected to hold steady or achieve small increases for 1992. Major U.S. auto manufacturers plan to produce cars and small trucks with more plastic components ranging from fenders (some 1993 Chrysler models) to all-body panels (General Motor's planned electric cars for 1994) to meet the demands for fuel efficiency, which is most readily achieved by weight reduction. With the anticipated price reductions, due mostly to improved processing methods, polymer composites should resume penetration of the aerospace, corrosion-resistant products and electrical markets. The long-term outlook for polymer composites is continued growth.

The increased use of polymer composites in military aircraft during the past 20 years has proven that they can perform in critical applications. The concern for increased fuel efficiency in the commercial aerospace market is driving the penetration of APC's into this

field of application. Long-range projections for commercial aircraft indicate record growth. It is expected that almost 10,000 planes valued at \$626 billion will be delivered between 1990 and 2005 according to a Kline & Co. report.⁴⁷

Starting in 1992, after having increased percentages annually, the Department of Defense requires that a minimum of 50% of PAN carbon fiber procured for the military be obtained from domestic sources. This requirement has driven increases in domestic capacity. But expected cuts in defense orders have dampened expectations of continued growth at rates greater than 15% to 20% annually for this advanced reinforcing element.⁴⁸

Reduction of costs through more efficient production and the development of more nonmilitary applications are factors that should brighten the outlook for APC's.

ADVANCED ALLOYS, METAL MATRIX COMPOSITES, AND CARBON-CARBON COMPOSITES

Background

Definitions, Grades, and Specifications.—Metallic alloys are materials formed by combining one metal with other metal(s) or nonmetal(s) to develop a new material that has physical, mechanical, and/or thermal properties superior to the original materials. Steels (iron-carbon), stainless steels (iron-chromium-nickel), brasses (copper-zinc), bronzes (copper-tin), and aluminum alloys are the most widely known alloys. New compositions of these and other alloys are constantly being developed. Advanced alloys are usually highly complex materials, such as the superalloys that contain nickel or cobalt with significant amounts of chromium and are used frequently at temperatures above 500° C. The superalloys are perhaps the oldest of the advanced materials, originally developed for aircraft engines during World War II. Even though

alloys originated so long ago that we use some of them to name the ages of humankind, there have recently been major advances in developing superalloys, powder metal applications, light metal alloys, metal matrix composites (MMC's), and others, as well as new processing technology. These developments have been a major contributor to the current interest in advanced materials. Compositions of typical superalloys, their room temperature and high-temperature strengths, and their applications are shown in table 14.⁴⁹ (See table 14.)

For many years, aluminum alloys, superalloys, and titanium alloys have been the "backbone" high-performance metals used in both civilian and military aerospace systems. With the military applications leading the way, these systems have long represented the highest of "high tech" in structural materials. Aluminum alloys have been the main material for airframes, while the heavier superalloys and for some components, titanium alloys, have been the enabling technologies for aircraft engines. While new processing techniques have resulted in performance improvements in these alloys, they are currently approaching their technological limits. The development of a new generation of materials is necessary to achieve the dramatic performance improvements needed to sustain U.S. dominance in the worldwide aerospace industry. While ceramics and polymer matrix composites will undoubtedly be significant members of this new family of materials, new metal-based systems will also be important. Included among the most promising of these new metal systems are MMC's, intermetallics, and new aluminum alloys.

MMC's are metals or metal alloys reinforced with ceramic fibers, whiskers, or particulates. Because of their superior mechanical strength and unique physical characteristics, such as low thermal expansion, MMC's find applications in structural and nonstructural components alike. They combine metallic properties (ductility and toughness) with ceramic properties (high-temperature strength and

high stiffness) to offer greater strength in shear and compression and higher surface temperature capabilities. Some laboratory development of MMC's began in the 1960's, but the first commercial application was an MMC diesel engine piston introduced in 1983 by Toyota. Since then nearly every automobilemaker has done some R&D on this application. The continued increase in interest in MMC's for applications in aerospace, automotive, and other markets has been enhanced by the availability of relatively inexpensive reinforcements. For example, the average price for silicon carbide particulate used in aluminum MMC's is about \$2.50 per pound. Also helpful is the technique of simply "inserting" a part made of new material into an existing assembly when the match is close enough in geometry and properties between the old and new part. This technique gives a manufacturer valuable experience in utilization of the new material.

Aluminum alloys are heavily predominant as metal matrix materials, followed by magnesium, copper, and titanium alloys. Reinforcement materials for MMC's include the compounds silicon and boron carbides (SiC, B₄C), silicon and aluminum nitrides (Si₃N₄, AlN), and oxides (Al₂O₃, SiO₂), as well as elemental materials, such as carbon. Examples of use include silicon carbide in aluminum and magnesium MMC's in all three standard forms (fiber, whisker, and particulate). Carbon is ordinarily used as a continuous fiber reinforcement. Discontinuously reinforced MMC's employ particulates, whiskers, or short fibers as reinforcing components. Table 15 lists the currently available fibers, whiskers, and particulates for reinforcing aluminum in composites. The suitability of these materials for fabrication by standard metalworking processes has brought considerable attention to this class of MMC's in recent years.

Carbon-carbon composites have unique properties. They are lightweight, have high strength, and maintain their properties to temperatures above 2,000° C (3,650° F) in nonoxidizing atmospheres. Above 425° C (800° F),

they must be coated or contain oxidation inhibitors to be used long term in an oxidizing atmosphere. They have high modulus and low creep. (They are stiff and deform only slightly at high temperatures under load over time.) Their high strength and low coefficient of thermal expansion provide good thermal shock resistance. (See table 15.)

Industry Structure.—Neither metal matrix nor carbon-carbon composites have reached a mature industry level. Both are still growing, in the number of applications as well as in the amount and value of material produced. Figures 7 and 8 show that both industries are dominated by small- to medium-sized companies, an indication of continued growth potential. (See figures 7 and 8.)

Technology.—Processing.—Metal refining methods, such as vacuum induction melting, vacuum arc remelting, and electroslag remelting, have allowed metallurgists to produce alloys of high cleanliness and extremely low impurity levels. New processing methods, such as directional solidification, single crystal growth, hot isostatic pressing, mechanical alloying, and rapid solidification, have been used to fabricate alloys with refined and controlled microstructures, resulting in the achievement of tailormade properties.

In some cases these new processes enable the production of "impossible alloys." Just as oil and water "do not mix," some metallic elements do not form solutions with each other. Through ordinary solidification, these insoluble metals would separate into at least two separate phases, and any product made would likely be brittle. But by using rapid (through millions of degrees per second) solidification, atoms of the different metals are "frozen" together before they have time to separate, forming a solid solution that could never be produced with conventional processing.

The fabrication of MMC's can range in complexity, from simple pouring of molten metal into molds containing

preformed fiber reinforcement skeletons, to intricate methods involving partially solidified metal, vigorous agitation, and/or the use of high pressure or vacuum to quickly force the molten metal into a mold. Each method offers its own particular advantages in terms of cost, protection of reinforcement, and adaptability. A number of processing methods suitable for advanced structural ceramics are also applicable to MMC's.

MMC's are often processed in two stages. First, a special process is used to produce a composite "preform" containing the specified amounts of reinforcement and matrix. Then standard metalworking processes are used to shape the composite to the desired configuration. For example, composite preforms can be fabricated by coating carbon fibers with condensed aluminum vapors using either chemical or physical vapor deposition. These carbon-reinforced aluminum preforms are subsequently consolidated using hot pressing techniques. Hot rolling or hot isostatic pressing could also be used for the consolidation step.

"Compcasting" is another technique for preparing MMC's. The reinforcing particles are introduced into a vigorously agitated, nearly solidified melt or slurry. The viscosity of the melt or slurry is controlled to maintain a uniform distribution of the reinforcement.

The Duralcan process involves adding SiC powder to aluminum alloys. Proprietary pretreatment of the particles and a specially designed stirrer to mix the particles in the melt are the technical keys to the process. After mixing, the composite is solidified relatively quickly using a direct chill water cooled mold. This preserves the uniform distribution of reinforcement particles. The ingots produced are then remelted and cast into the desired shapes. More than 70 foundries have successfully remelted and cast ingots from this process.⁵⁰

Applications.—MMC's are already used in several applications. Boron-fiber-reinforced aluminum tubes are used as cargo bay struts in the space shuttle and some sporting and recreational goods

such as skis and bicycle frames. Aluminum-base MMC's are finding additional applications in airframes and other aircraft applications.

Lockheed is using MMC's in the vertical tail fins for the Advanced Tactical Fighter. This application results in a 25% weight reduction over current tail fins. Pratt and Whitney Aircraft is developing a fan blade for jet engines, utilizing an aluminum matrix composite with continuous boron fiber reinforcement wrapped around a titanium core. Aerospace optical systems requiring high stiffness and low coefficient of thermal expansion (CTE) have been produced using Duralcan composites.

Duralcan automotive brake rotors save one-third of the weight of cast iron rotors and have low thermal expansion, better wear resistance, and excellent thermal conductivity. Automotive pistons take advantage of this composite's high wear resistance, low CTE, and high-temperature strength. Additional automotive applications will include rocker arms and cylinder heads.

Other products fabricated in foundries using Duralcan include microelectronics packaging, electro-optical platforms, ballistic armor, and various structures requiring stiffness and good high-temperature properties.⁵¹

The future will bring titanium-base MMC's now being developed for turbojet compressors and superalloy-base MMC's for thrust turbine airfoils. Potential commercial applications of MMC's are listed along with their special properties in table 16. (See table 16.)

Recycling.—In the metals industry, making use of alloy scrap is common practice. Scrap metal is usually less expensive than primary metal and sometimes more available. There can be a problem, however, with contamination in any complex alloy, especially the superalloys. The recycling chain begins with scrap produced from alloy production with contributions of "prompt scrap" from parts fabricators and other users of superalloys, mainly builders of engines for commercial airliners or military aircraft. A user is any

organization that uses a finished product until the product is retired from service owing to wear, corrosion, inefficiency, or obsolescence. The user generates "obsolete scrap" when equipment is overhauled and parts replaced, or when equipment is dismantled at the end of its useful "lifecycle." The scrap is usually in the form of solids, such as turbine blades and vanes. A recent U.S. Bureau of Mines study indicates that while most of the superalloy scrap generated is recycled into new superalloys, up to 30% of it is downgraded or discarded. This represents an area where research is needed to maximize conservation of these valuable materials.⁵²

Because the reinforcement elements would become a contaminant if allowed to remain mixed with the matrix material during remelting, segregation of MMC's from nonreinforced alloys is necessary before recycling. Bureau research has shown that it is possible to separate conventional Ti-6Al-4V alloy from the same alloys reinforced with SiC or B₄C fibers using eddy current measurements. Bureau researchers have succeeded in separating aluminum alloys from aluminum-lithium alloys using eddy current measurements. Because these techniques make use of differences in electrical conductivity to make the separation, they should work for separating aluminum metal matrix composites from unreinforced aluminum alloys.

If the metal and reinforcement do not interact chemically at the melting point of the metal, a physical separation, such as filtration, would be effective in separating matrix material from reinforcements. The U.S. Bureau of Mines has conducted preliminary research on this approach using various filter media.⁵³ However, if significant chemical reactions occur, the fibers usually will be damaged, and often special techniques would be needed to clean up the now contaminated melt. Currently, the amount of MMC's producing obsolete scrap is very low, but recycling is expected to increase significantly as the acceptance of these materials increases.

Significant amounts of recycling already occur with certain MMC's. Contrary to the commonly held impression that MMC's are always difficult to recycle, the Duralcan MMC foundry ingot is inherently recyclable because when it is remelted and cast to shape in the foundry, after original purchase, the reinforcing particles remain well distributed with only gentle stirring and there is no loss of properties. Theoretically, when its useful life is completed, the product could be remelted and cast still another time. Currently, most of the scrap recycled is prompt scrap, gates and risers from foundry ingot, extrusion butts, cut extrusion scrap, etc. This material is recycled back through the basic Duralcan composite stirring process.

If desired, the reinforcing particulate can be removed from the molten composite by the same fluxing methods, such as salt fluxing, used to remove oxide films, etc., from ordinary aluminum alloys. The result is an aluminum alloy, free of particulate, "reclaimed" to its original alloy state before the composite was produced.

Annual Review

Consumption and Uses.—The estimated 1991 U.S. market for 330,000 pounds of metal matrix composites is \$33 million or 61% of the world market. This represents an 8.3% decrease in value and weight compared with those of 1990. Figure 9 (Kline & Co.) shows the 1991 U.S. market by end-use industry. These data show \$4 million (170,000 pounds) for automotive; \$26 million (145,000 pounds) for aerospace; \$2 million (10,000 pounds) for recreational; and \$1 million (5,000 pounds) for other. The heavy use of metal matrix composites in aerospace programs and current and anticipated cutbacks in these programs helps explain why there was a decrease in value produced and a drop in how much material was consumed. (See figure 9.)

Kline & Co.'s estimated 1991 U.S. market for 375,000 pounds of carbon-carbon composites is \$125 million. This represents a 16.7% decrease in value and

a 25% drop in weight compared with those of 1990. Figure 10 (Kline & Co.) shows the 1991 U.S. market by end-use industry. These data show \$32 million (265,000 pounds) for aircraft brakes; \$67 million (50,000 pounds) for nose tips and ablatives; \$22 million (25,000 pounds) for rockets and nozzles; \$2 million (20,000 pounds) for racing brakes; and \$2 million (15,000 pounds) for other. The heavy use of carbon-carbon matrix composites in aircraft brakes helps explain why there was a decrease in value produced and material consumed. (See figure 10.)

World Review.—The estimated 1990 worldwide market for 1.2 million pounds of metal matrix composites was \$60 million for four different applications (figure 11): automotive (\$15.6 million), aerospace (\$42.0 million), recreation (\$1.2 million), and other (\$1.2 million), according to Kline & Co. In 1991, Kline & Co. reported that the world market dropped to \$54 million (10% decline), paralleling the sluggish domestic and world economies. Total usage also dropped to 980,000 pounds (18% decline) in 1991. Figure 12 shows data for the four applications: automotive (\$11 million), aerospace (\$40 million), recreation (\$1.5 million), and other (\$1.5 million). (See figures 11 and 12.)

A notable feature in figure 11 is the difference in the aerospace industry's share in terms of weight and dollar values; only 15% by weight, the aerospace share accounts for 70% of the value. This indicates that the average cost of MMC's for aerospace applications is an order of magnitude higher than those for automotive and other applications. These higher costs are attributed to labor-intensive fabrication and low-volume production.

Again, according to Kline & Co., in figure 13, North America accounted for 56% of the 1991 worldwide value of MMC's, mainly due to the high cost of composite materials used by the aerospace industry. The Pacific Rim (mostly Japan) share is only 20% of this worldwide market in terms of value.

However, it should be noted that Japan is the leading consumer of MMC components, in terms of weight, mainly because of its production of MMC engine pistons. For 1991, the Pacific Rim production was 45% of the world total by weight. North America was rated at only 36% on the same basis. It appears that a variety of aerospace applications will become large markets for MMC's. Military jet and rocket structures are specific target areas for MMC's. (See figure 13.)

The estimated worldwide market in 1990 for carbon-carbon composites was \$200 million for four different applications (figure 14): aircraft brakes (\$50 million), rocket nozzles (\$70 million), nose tips-ablatives (\$64 million), and other (\$16 million). According to Kline & Co., the United States represented 75% of the 1990 worldwide carbon-carbon composite market, primarily owing to its dominance in military and aerospace technology. Western Europe and Japan account for the remaining 25% of market share. (See figure 14.)

In spite of recent predictions of more than 10% growth per year, the estimated world market for carbon-carbon composites in 1991 is estimated as shown in figure 15 to be only \$175 million, with aircraft brakes and rocket nozzles dropping down below \$40 million, while nose-tips and ablatives increased to \$90 million and other uses held steady. The total usage dropped from 675,000 to 515,000 pounds. This decrease is due to an overall sluggish economy combined with current and anticipated cuts in defense spending owing to the winding down of the cold war and the quick success in the Persian Gulf war. Figure 16 shows that the United States maintained its position holding 74% of the market share. (See figures 15 and 16.)

Current Research.—Matrix fiber adherence is an important factor in determining MMC properties. Optimum adherence of the matrix to the reinforcement often involves some degree

of chemical reaction between the matrix and the reinforcement. However, if the reaction is too extensive, degradation of the reinforcement may limit the strength of the composite. The lithium added to aluminum alloys to enhance wetting during the formation of aluminum-alumina fiber composites (in addition to adding strength and stiffness to the matrix) reacts strongly with the fibers. The composite must be infiltrated and cooled quickly or the Al_2O_3 fibers will lose their integrity and will add nothing to the properties of the composite. In another example, nonheat-treated boron-fiber-reinforced aluminum fails during fracture through debonding at the fiber-matrix interface. After heat treatment of the composite at 300° C, in an inert atmosphere, the room temperature strength increases and fracture occurs within the fiber itself, rather than along the fiber-matrix interface. Through a properly controlled reaction, the interface has become stronger than the fiber. Additional research is necessary to improve the ability of the materials engineer to control the reactions at the fiber-matrix interface to develop optimum adherence between the reinforcing phase and the matrix.

The most recent developments in MMC technology utilize the wrought alloy series rather than the casting alloys as a basis for matrix materials. BP Metal Composites in England is developing composites based on Alloy 2124, a high-strength, fracture tough alloy, and Al-Li Alloy 8090, a new, strong, stiff alloy with lithium, using 17% SiC particles for reinforcements for both. The resulting composites have excellent stiffness. Composite billets are made using powder metallurgy techniques. Conventional and superplastic metalworking techniques are then used to form sheet, plate, extrusions, forgings, or specific parts. Access panels, extruded floor-beam struts, and missile control fins have been fabricated as demonstration aerospace parts.⁵⁴

Advanced Composite Materials Corp. (ACMC) of Greer, SC, is also developing aluminum composites based on the wrought alloy series. Their composite 2009/SiC has the strength and density of

high-strength 7XXX aircraft alloys and the stiffness of titanium. Alloy 2009 contains 3.6% copper and 1.3% manganese. Powder metallurgy techniques are used to produce billets, which are then extruded, rolled, or forged. They can be processed by any metalworking operation that does not require melting. The finished products are stronger and more ductile than equivalent ones made from cast billets. Any desired product can be fabricated using conventional shop procedures. Lockheed is currently testing prototypes of a vertical tail stabilizer for an advanced jet fighter made from this material.⁵⁵ ACMC is also exploring the 6XXX series aluminum alloys (which contain magnesium and silicon as alloying elements) and high-temperature aluminum alloys made by rapid solidification for use as matrix materials for composites.⁵⁶

Outlook

The already intense intermaterial competition between different materials systems for the various sectors of industry will increase in the near and long term due to anticipated decreases in defense spending. For the materials systems that have been able to take advantage of the performance at any price philosophy of military procurement, there is danger of near-term downturns in applications because this philosophy can no longer prevail. In the ordinary consumer world, the materials that provide adequate performance at the best price will prevail; the continued success of much of the new materials industry will be dependent on the ability of developers to find effective nonmilitary applications of these materials. For any materials that are heavily dependent on military applications, the picture has become cloudy, at best. The bright side of this phenomenon is that more work in the development of commercial applications will become imperative, rather than an afterthought. With more emphasis on commercial applications of these new materials the United States is more likely to succeed in the economic "wars."

New alloys that are lighter, stronger, tougher, more fatigue and corrosion resistant will always find increasing use if they can be manufactured at competitive prices. Thus, new aluminum and magnesium alloys will continue to chip away at the dominance of steel where lower density has become a desired property as in the automobile industry. New titanium alloys will be applied in cases where lightweight and good high-temperature properties are important.

MMC's saw a drop in nearly all areas in 1991. The only bright spot was in the recreation area, where performance at any price is second only to defense applications. In this area, an excellent 25% increase in sales occurred, overcoming a 10% drop for the entire MMC sector. As more commercial applications are developed, the MMC industry should resume its growth.

Because of its heavy use in defense applications, perhaps the picture for carbon-carbon composites is the most cloudy. To meet the mandated requirement for a 50% domestic supply of PAN fibers, domestic capacity has been increasing over the past few years. Demand has not kept up. Capacity has outstripped demand both domestically and worldwide. At slightly more than \$300 per pound for an average price, this material is quite expensive. Accordingly, most of its growth must occur in sectors where no competing material can come close to doing the job. Therefore, opportunities for growth appear to be somewhat limited for the near term, until more varied applications of this material can be found.

POWDER METALLURGY

Powder metallurgy (P/M) is an ancient technique. The tungsten filament produced in 1910 for the electric light was the first modern P/M product. More recently, the 1970's saw rapid solidification processing (RSP) become a powder production method, and the 1990's have seen the development of metal injection molding (MIM) as a parts production method.

Background

Definitions, Grades, and Specifications.—P/M is a high precision method of forming metal components. The use of P/M permits the fabrication of complex metal shapes with little or no machining, provides excellent control over dimensional tolerances and surface finishes, and decreases scrap losses when compared to conventional metalworking processes.

Products for Trade and Industry.—Iron, stainless steels, aluminum, copper, brasses, bronzes, nickel, and tin are the most commonly used powder metals and alloys. Other important factors in the P/M industry are titanium, the compound tungsten carbide, and the refractory metals tungsten, molybdenum, and tantalum.

Industry Structure.—There are about 50 domestic producers of powder metals and about 200 fabricators of parts using these materials. About 70 fabricators manufacture specialty P/M products like superalloys, tool steels, porous alloy products, magnetic materials, RSP and MIM products, alloy strip for electronic applications, and tungsten carbide cutting and wear parts, etc. The majority of P/M fabricators produce conventional P/M products from mostly iron- and copper-base powders.

Technology.—Processing.—The most common methods of powder production are reduction of oxides or other chemicals, electrolysis, and atomization of molten metal. RSP is a newer method for powder metal production. In this process the molten alloy is solidified at rates equivalent to millions of degrees per second. RSP is used to produce wrought aluminum alloys that are stronger and have greater fracture toughness, corrosion, and fatigue resistance than conventionally produced aluminum alloys.

The basic method used to produce parts from powder metals involves high

pressures and heat. The powder is pressed in a precision die at pressures up to 50 tons per square inch to form a useful shape such as a gear. Ordinarily, the powder is pressed at room temperature and then heated in a controlled atmosphere so that a metallurgical bond is formed between the powder particles. No melting occurs during this sintering process. The bulk density of the powder increases during both the pressing and sintering processes so that the finished product is as dense or nearly so, compared to a product made using a molten metal step.

Other processes used for powder metal consolidation include hot or cold isostatic pressing, forging, direct powder rolling, and MIM, a newly developed method. In MIM processing, fine metal powders are injected into a mold along with an organic binder, such as wax. The organic binder is burned off from the molded part, and the component is sintered to final shape. It is possible to produce very complex parts of many sizes and shapes using MIM.

Design engineers are becoming more comfortable with MIM and are designing parts for high-performance components. With the full implementation of MIM by the automotive industry, P/M could return to steady growth for some years. Current MIM automotive applications include ignition lock and truck manual transmission parts. GM and Chrysler are contemplating the use of MIM parts for small truck transmissions, fuel injection systems, and brakes. Even without major cost breakthroughs, total sales in the MIM area could reach \$100 million before the turn of the century.

Applications.—P/M parts are currently used in many different kinds of items, from lock hardware to Canadian nickels. P/M is utilized in various small- to medium-sized appliances such as power tools and hardware, copiers and postage meters, washing machines, garden tractors, snowmobiles, automatic transmissions for automobiles, and sporting equipment such as fishing rods and guns. Current domestic passenger cars contain about 25 pounds of P/M

parts. Although some of these applications appear mundane, it is the fabricator's use of advanced processing of new materials that gives them a competitive edge over other makers of similar products.

Annual Review

More than 800,000 tons of metal powder is produced annually, worldwide. The total value of domestic metal powder shipments, including paste and flake, was \$1.2 billion in 1990 when the amount produced in North America was slightly less than 300,000 tons. The powder metal parts and product industry is a \$2 billion business in North America, indicating that the value added during fabrication is nearly equal to that of the powder as a raw material. Shipments in the P/M industry decreased uniformly during 1991 as shown in table 17.⁵⁷ The slight decrease for each major area of the industry reflected continued downturns or slow recovery in the national economy. (See table 17.)

Outlook

The slight downturn for 1991 for powder metals was due to general economic conditions rather than a real softening of demand for powder metal products. The general trend for annual increases should resume in 1992, unless the general economy proves to be very sluggish. With greater implementation of new processes and the resulting increases in efficiency, growth should continue in this sector of the materials industry.

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TABLE 1
COMPARISON OF GOVERNMENT LISTS OF IMPORTANT TECHNOLOGIES

National critical technologies	Commerce emerging technologies	Defense critical technologies
Materials:		
Materials synthesis and processing and electronic and photonic materials	Advanced materials, advanced semiconductor devices, superconductors	Composite materials, semiconductor materials and microelectronic circuits, superconductors.
Ceramics, composites, high-performance metals and alloys	Advanced materials	Composite materials.
Manufacturing:		
Flexible computer-integrated manufacturing, intelligent processing equipment, micro- and nanofabrication, systems management technologies.	Flexible computer-integrated manufacturing and artificial intelligence.	Machine intelligence and robotics.
Information and communications:		
Software	High-performance computing	Software producibility.
Microelectronics and optoelectronics	Advanced semiconductor devices	Semiconductor materials and microelectronic circuits.
	Optoelectronics	Photonics.
High-performance computing and networking	High-performance computing	Parallel computer architectures.
High-definition imaging and displays	Digital imaging	Data fusion.
Sensors and signal processing	Sensor technology	Data fusion, signal processing, passive sensors, sensitive radars, machine intelligence and robotics.
Data storage and peripherals	High-density data storage	Photonics.
Computer simulation and modeling	High-performance computing	Simulation and modeling, and computational fluid dynamics.
Biotechnology and life sciences:		
Applied molecular biology and medical technology	Biotechnology and medical devices and diagnostics	Biotechnology materials and processes.
Aeronautics and surface transportation:		
Aeronautics and surface transportation technologies		Air-breathing propulsion.
Energy and environment:		
Energy technologies and pollution minimization, remediation, and waste management		No national critical technologies counterpart: high energy density materials, hypervelocity projectiles, pulsed power, signature control, and weapon system environment.

Note.—National critical technologies were designated by the National Critical Technologies Panel; emerging technologies were designated by the U.S. Department of Commerce; defense critical technologies were designated by the U.S. Department of Defense.

Source: National Critical Technologies Panel, Report of the National Critical Technologies Panel, Washington, DC, 1991.

TABLE 2
TOTAL AMPP R&D FUNDING, BY AGENCY

Department or agency	Fiscal year 1991 (appropriated)		Fiscal year 1992 (appropriated)		Fiscal year 1993 (President's budget)	
	Value (million dollars)	Percent	Value (million dollars)	Percent	Value (million dollars)	Percent
Department of Commerce, National Institute of Standards and Technology	44.5	2.7	46.2	2.8	48.0	2.6
Department of Defense	505.9	30.4	448.6	27.1	431.9	23.8
Department of Energy	593.9	35.7	602.7	36.4	677.9	37.3
Department of the Interior, Bureau of Mines	25.0	1.5	24.7	1.5	23.8	1.3
Department of Transportation	10.0	.6	8.8	.5	15.5	.8
Environmental Protection Agency	3.2	.2	3.5	.2	4.5	.2
Department of Health and Human Services, National Institutes of Health	66.6	4.0	76.6	4.6	81.7	4.5
National Aeronautics and Space Administration	116.3	7.0	124.5	7.5	153.5	8.4
National Science Foundation	246.0	14.8	265.9	16.0	318.5	17.5
Department of Agriculture	51.4	3.1	57.1	3.4	66.1	3.6
Total materials R&D funding	1,663.4	100.0	1,658.6	100.0	1,821.4	100.0

¹Equals 10% growth of fiscal year 1992.

Source: Committee on Materials, Office of Science and Technology Policy, Executive Office of the President.

TABLE 3
AMPP R&D FUNDING, BY RESEARCH COMPONENT

Component	Fiscal year 1991		Fiscal year 1992		Fiscal year 1993		Fiscal year 1993 growth over fiscal year 1992
	Value (million dollars)	Percent	Value (million dollars)	Percent	Value (million dollars)	Percent	Value (million dollars)
Synthesis and processing	670.1	40.3	682.9	41.2	747.7	41.0	64.8
Theory, modeling, and simulation	219.1	13.2	223.6	13.5	253.3	13.9	29.7
Materials characterization	481.2	28.9	473.8	28.6	503.0	27.6	29.2
Education/human resources	19.1	1.2	21.1	1.3	26.9	1.5	5.8
National user facilities/other	273.8	16.4	257.2	15.5	290.5	15.9	33.3
Total component funding	1,663.4	100.0	1,658.6	100.0	1,821.4	100.0	162.8

TABLE 4
FISCAL YEAR 1993 AMPP R&D FUNDING, BY MATERIALS CLASS AND AGENCY¹

(Million dollars)

Materials class	DOC	DOD	DOE	DOI	DOT	EPA	HHS	NASA	NSF	USDA	Total ²
Bio/biomolecular materials	0.2	19.6	2.5	—	0.1	—	81.7	4.0	23.0	56.3	187.4
Ceramics	5.8	22.4	90.6	2.1	—	0.8	—	1.3	19.5	—	150.5
Composites	4.0	86.1	29.5	.9	2.4	—	—	69.9	12.1	1.1	206.8
Electronic	6.1	58.5	43.8	—	—	.3	—	12.2	55.0	—	176.7
Magnetic	1.2	2.0	8.5	—	28.1	—	38.7	1.3	14.7	—	27.7
Metals	9.0	36.1	122.9	5.1	3.8	.4	—	18.7	33.0	—	228.9
Optical/photonic	.8	71.9	28.1	—	—	—	—	5.2	32.7	—	138.8
Polymers	5.1	23.1	20.4	—	—	.5	—	12.6	22.9	8.7	93.2
Superconducting	3.2	68.5	38.7	—	.1	—	—	5.4	26.9	—	142.9
Total² specific materials R&D	35.4	388.2	384.9	8.1	6.4	2.0	81.7	138.7	241.5	66.1	1,352.9
Other/nonspecific materials R&D	12.6	43.7	293.0	15.8	9.1	2.5	—	14.8	77.0	—	468.5
Total² materials R&D	48.0	431.9	677.9	23.8	15.5	4.5	81.7	153.5	318.5	66.1	1,821.4

¹DOC—U.S. Department of Commerce/National Institute of Standards and Technology, DOD—U.S. Department of Defense, DOE—U.S. Department of Energy, DOI—U.S. Department of the Interior, DOT—U.S. Department of Transportation, EPA—Environmental Protection Agency, HHS/NIH—U.S. Department of Health and Human Services/National Institutes of Health, NASA—National Aeronautics and Space Administration, NRC—National Research Council, NSF—National Science Foundation, USDA—U.S. Department of Agriculture.

²Data may not add to totals shown to rounding because of independent.

Source: Committee on Materials, Office of Science and Technology Policy, Executive Office of the President.

TABLE 5
DOMESTIC PRODUCTION FOR ADVANCED MATERIALS

Year	Advanced ceramics (Ceramic industry)		Polymer composites (SPI Composites Institute)		Advanced polymer composites (Kline)		Metal matrix composites (Kline)		Carbon-carbon composites (Kline)	
	Quantity (million pounds)	Value (billion dollars)	Quantity (million pounds)	Value (billion dollars)	Quantity (million pounds)	Value (billion dollars)	Quantity (thousand pounds)	Value (million dollars)	Quantity (thousand pounds)	Value (million dollars)
1990	—	3.8	2,575	—	19.8	2.4	360	36	500	150
1991	—	3.9	2,360	—	17.1	2.4	330	33	375	125

TABLE 6
WORLD PRODUCTION FOR ADVANCED MATERIALS

Year	Advanced ceramics (Ceramic industry)		Polymer composites (SPI Composites Institute)		Advanced polymer composites (Kline)		Metal-matrix composites (Kline)		Carbon-carbon composites (Kline)	
	Quantity (million pounds)	Value (billion dollars)	Quantity (million pounds)	Value (billion dollars)	Quantity (million pounds)	Value (billion dollars)	Quantity (thousand pounds)	Value (million dollars)	Quantity (thousand pounds)	Value (million dollars)
1990	NA	13.6	NA	NA	33.0	4.0	1,200	60	675	200
1991	NA	15.3	NA	NA	31.1	4.5	980	54	515	175

NA Not available.

TABLE 7
U.S. SALES OF ADVANCED CERAMICS

(Million dollars)

Year	Low-voltage porcelain	Capacitors packaging	Engineering ceramics	Other electronics	Optical fiber	Other ¹	Total
1987	1,151	888	976	354	459	547	4,376
1988	1,132	1,199	851	434	317	593	4,526
1989	1,157	724	896	467	420	514	4,287
1990	NA	NA	NA	NA	NA	NA	3,840
1991	NA	NA	NA	NA	NA	NA	3,938

NA Not available; only total U.S. values were available in 1990 and 1991.

¹The categories of ferrites and high-voltage porcelain are included in "Other."

Source: Ceramic Industry.

TABLE 8
WORLD SALES OF ADVANCED CERAMICS¹

(Million dollars)

Year	Low-voltage porcelain	Capacitors packaging	Engineering ceramics	Other electronics	Optical fiber	Other ²	Total
1990	1,663	6,525	1,359	2,310	1,224	513	13,594
1991	1,534	5,753	1,688	3,758	1,994	614	15,341

¹Represents total worldwide sales by category for the top 145 producers in 1990 and 132 producers in 1991.

²The categories of ferrites and high-voltage porcelain are included in "Other."

Source: Ceramic Industry.

TABLE 9
U.S. SALES OF CERAMICS, BY MAJOR CATEGORY

(Million dollars)

Year	Structured clay ¹	Glass	Advanced ceramics	Porcelain	Whitewares	Refractories	Total
1987	—	17,574	4,376	4,569	2,908	1,678	31,105
1988	—	20,553	4,526	4,649	3,040	1,985	34,753
1989	—	18,558	4,287	5,486	3,459	2,156	33,946
1990	—	18,100	3,840	5,680	3,420	1,620	32,660
1991	297	17,162	3,938	5,475	3,530	1,730	32,132

¹First appearance in Ceramic Industry magazine's industry profile.

Source: Ceramic Industry.

TABLE 10
WORLD SALES OF CERAMICS, BY MAJOR CATEGORY

(Million dollars)

Year	Structured clay ¹	Glass	Advanced ceramics	Porcelain	White-ware	Refractories	Total
1990	—	41,200	13,594	7,400	6,100	4,800	73,094
1991	1,011	44,152	15,342	7,670	8,223	5,857	82,215

¹First appearance in Ceramic Industry magazine's industry profile.

Source: Ceramic Industry.

TABLE 11
POLYMER MATRIX COMPOSITES FABRICATION METHODS OPEN MOLD TECHNIQUES

Process	Predominate polymer processed	Materials type or form	Shape characteristics	Process description
Open mold (contact molding)	Thermosetting (primary reinforced polymer forming process 40% of total)	Liquid resin (spray, hand applied) or thermoplastic sheet; reinforcing material	Large complex	Reinforced shapes are formed by using open molds, and room-temperature curing resin is brushed, poured, or sprayed onto reinforcing material laid up in a mold. Spray up method resin and chopped fibers sprayed onto mold. Reinforced vacuum formed sheet method—mainly acrylic sheet is vacuum formed and reinforced resin applied to back surface. The process also includes encapsulating or potting.
Continuous laminating	Polyester	Resin, reinforcement	Thin, flat or curved profiles	Reinforcement is passed through a resin bath, faced with cellophane, passed through squeeze rolls, and heated.
Filament winding	Epoxy, polyester	Resin	Round, rigid	Continuous filament (usually glass) in form of roving is saturated with resin and machine wound onto mandrels having shape of desired finished part. Once winding is completed, part and mandrel are placed in oven for curing. Mandrel is then removed through porthole at end of wound part.
Pultrusion	Thermosetting (polyesters, some epoxies, and others)	Liquid resins, fiber reinforcement	Uniform cross section	Resin-swelled fibers are pulled through a heated shaping die, which initiates cure in the thermosetting resin and forms the shape of the continuous length of pultruded product.
Centrifugal casting	Thermosetting	Liquid resin, fiber reinforcement	Uniform wall thickness	Resin is applied to the inside of a rotating cylindrical mold and is uniformly forced against the reinforcing material. Heating aids flowing and curing.

TABLE 12
POLYMER MATRIX COMPOSITES FABRICATION METHODS CLOSED MOLD TECHNIQUES

Process	Predominate polymer processed	Materials type or form	Shape characteristics	Process description
Reaction injection molding (RIM)	Thermosetting (urethanes)	Liquid	Large, intricate, high-performance, solid, or cellular	Reactive components are generally mixed by impingement in a chamber and then injected into a closed mold.
Laminates, high pressure-industrial and decorative	Thermosetting	Reinforcement—fiber sheet/prepregs, liquid resin	Thick walled, simple shapes	Reinforcing material (layers) is preimpregnated or soaked with resin (sometimes a thermoplastic). Compressed under pressure over 1,000 pounds per square inch into a flat sheet. Tube and rod shapes also made from rolled or closed mold methods. Prepregs are semicured reinforced materials used to make above forms. Decorative laminates may have a separate patterned face-sheet laminated to the structure.
Match die molding (low pressure)	Thermosetting (epoxy, polyester, and others)	Reinforced plastic compounds or resin and reinforcing material	Contoured, medium wall thickness	Either preforms (chopped glass fibers/resin shape) or a premix molding compound (resin and short glass fiber strands) are placed in mold, heated, and pressed to shape.

TABLE 13
U.S. POLYMER COMPOSITES SHIPMENTS¹

(Million pounds)

Markets	1987	1988	1989	1990	1991
Aircraft/aerospace/military	36	39	41	39	39
Appliance/business equipment	141	150	151	153	135
Construction	506	495	470	468	420
Consumer products	167	169	158	165	149
Corrosion-resistant equipment	329	349	335	350	355
Electrical/electronic	214	230	229	241	231
Marine	413	452	405	375	275
Transportation	656	695	677	705	682
Other	75	80	76	79	74
Total	2,537	2,659	2,542	2,575	2,360

¹Includes thermoset and thermoplastic resin composites, reinforcements, and fillers.

Source: SPI Composites Institute.

TABLE 14
COMPOSITIONS OF TYPICAL SUPERALLOYS¹

Alloy	Composition percent						Room-temperature tensile strength (1,000 psi)	High-temperature tensile strength at X °F (1,000 psi)	Uses
	Cr	Ni	Co	Mo	W	Fe			
Fe-Ni-base:									
19-9DL	19.0	9.0	—	1.25	1.25	66.8	118	89 at 1,000	Gas turbine parts, etc.
Incoloy 800	21.0	32.5	—	—	—	45.7	88	55 at 1,200	Do.
A-286	15.0	26.0	—	1.25	—	55.2	146	104 at 1,200	Do.
V-57	14.8	27.0	—	1.25	—	48.6	172	129 at 1,200	Do.
Incoloy 901	12.5	42.5	—	6.0	—	36.2	90	75 at 1,200	Do.
Inconel 718	19.0	52.5	—	3.0	—	18.5	208	185 at 1,000	Aircraft turbine parts, rocket motors.
Hastelloy X	22.0	49.0	1.5 ²	9.0	.6	15.8	114	94 at 1,200	Turbine and furnace parts, petrochemical equipment.
Ni-base:									
Waspaloy	19.5	57.0	13.5	4.3	—	2.0 ²	188	165 at 1,200	Jet engines, missiles.
Udimet 500	19.0	48.0	19.0	4.0	—	4.0 ²	197	175 at 1,200	Do.
Udimet 700	15.0	53.0	18.5	5.0	—	<1.0	205	180 at 1,200	Do.
IN-100	10.0	60.0	15.0	3.0	—	<.6	147	158 at 1,000	Turbine blades.
Inconel X-750	15.5	70.0	—	—	—	7.0	162	140 at 1,000	Turbine parts.
René 41	19.0	51.0	11.0	9.5	—	5.0	206	194 at 1,200	Jet engines, missiles, etc.
Co-base:									
Haynes 25 (L-605)	20.0	10.0	50.0	—	15.0	3.0	135	47 at 1,600	Where corrosion resistance and strength are required at high temperature.
Haynes 188	22.0	22.0	37.0	—	14.5	3.0 ²	137	106 at 1,200	Gas turbine and aerospace parts requiring high-temperature strength and oxidation resistance.
S-816	20.0	20.0	42.0	4.0	4.0	4.0	140	73 at 1,500	Where corrosion resistance and strength are required at high temperature.
X-40	22.0	10.0	57.5	—	7.5	1.5	108	76 at 1,200	Turbine blades and wheels.
WI-52	21.0	—	63.5	—	11.0	2.0	110	108 at 1,200	Do.
MAR-M 302	21.5	—	58.0	—	10.0	.5	140	92 at 1,500	Jet engines.
MAR-M 509	23.5	10.0	54.5	—	7.0	—	113	80 at 1,200	Do.
J-1570	20.0	28.0	46.0	—	—	2.0	—	132 at 1,200	Aircraft gas turbines, high-temperature sheet.

¹Cr—Chromium, Ni—nickel, Co—cobalt, Mo—molybdenum, W—tungsten, Fe—iron.

²Maximum percentage of composition.

Sources: Metals Handbook Desk Edition, 1985; Materials Engineering Materials Selector, 1991.

TABLE 15
ALUMINUM MATRIX COMPOSITES

Reinforcement material ¹	Percent (by volume)	Tensile strength (MPa)	Elastic modulus (GPa)	Density (g/cm ³)
None	—	140-620	70	2.70
B(c)	50	1,380	230	2.49
Al ₂ O ₃ (f)	50	1,170	210	3.60
SiC(c)	50	1,480	230	2.93
SiC(w)	20	340	100	2.80
Graphite(c)	41	620	320	2.44
SiC(p)	15	455	97	2.77

¹C—Continuous fiber, f—fiber, w—whisker, p—particulate.

TABLE 16
POTENTIAL COMMERCIAL APPLICATIONS OF METAL MATRIX COMPOSITES

Application	Desired properties	Anticipated composite system(s) ¹
Automotive:		
Engine blocks	Lightweight heat resistance, strength, stiffness	SiC ¹ /Al
Push (connecting rods)	do.	SiC ² /Al, B/Al
Frames	Lightweight, strength, stiffness	SiC ¹ /Al
Springs	do.	SiC ² /Al
Piston rods and inserts	do.	SiC ¹ /Al
Battery plates	Stiffness	Gr/Pb
Driveshaft		
Electrical:		
Motor brushes and heat sinks	Electrical conductivity, wear resistance	Gr/Cu
Cable, electrical contacts	Electrical conductivity, strength	Gr/Cu
Utility battery plates	Stiffness, strength, corrosion resistance	Al ₂ O ₃ /Pb, Gr/Pb, fiberglass/Pb
Medical:		
X-ray tables	Lightweight, stiffness, strength	B/Al, SiC ² /Al
Prosthetics	do.	B/Al, SiC ² /Al
Wheelchairs	do.	B/Al, SiC ² /Al
Orthofies	do.	B/Al, SiC ² /Al
Walkers/canes		
Sports equipment:		
Tennis racquets	do.	B/Al, Gr/Al, SiC ¹ /Al
Ski poles	do.	B/Al, Gr/Al, SiC ¹ /Al
Skis	do.	B/Al, Gr/Al, SiC ¹ /Al
Fishing rods	Lightweight, strength, flexibility	B/Al, Gr/Al, SiC ¹ /Al
Golf clubs	do.	B/Al, Gr/Al, SiC ¹ /Al
Bicycle frames	Lightweight, strength, stiffness	B/Al, Gr/Al, SiC ¹ /Al
Motorcycle frames	do.	B/Al, Gr/Al, SiC ¹ /Al
Textile industry:		
Shuttles	Lightweight, wear resistance	B/Al, Gr/Al, SiC ² /Al
Looms	do.	B/Al, Gr/Al, SiC ² /Al
Other:		
Bearings		Gr/Pb
Chemical process equipment		Al ₂ O ₃ /Pb
Abrasive tools		B/Al ₂ O ₃ , SiC/Al ₂ O ₃
Robotic manipulator arms		B/Al, Gr/Al, SiC ² /Al

¹SiC whisker and/or continuous SiC filament.

²SiC whiskers only.

TABLE 17
NORTH AMERICAN METAL POWDER SHIPMENTS

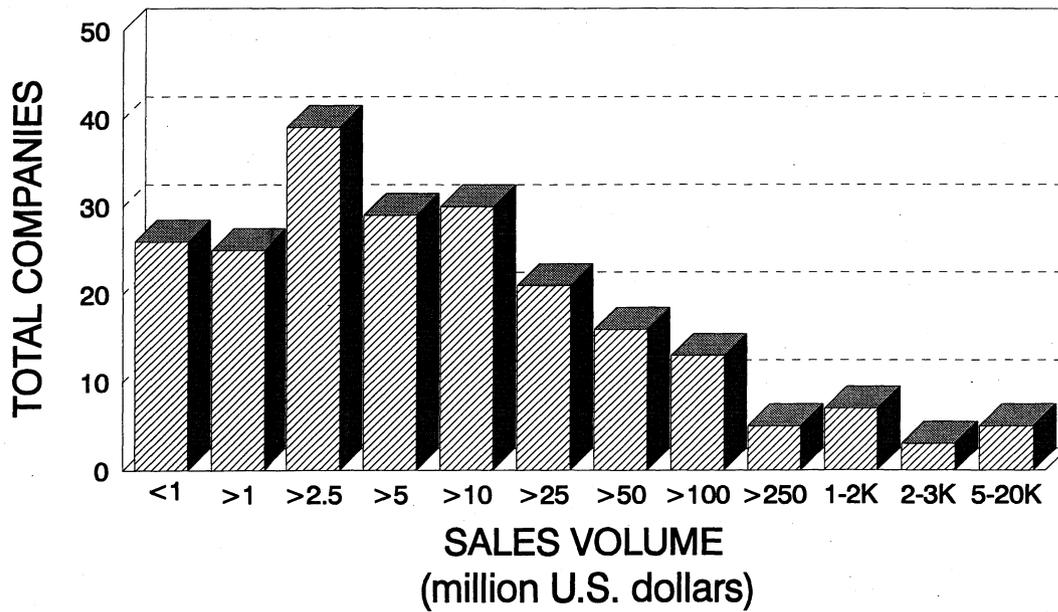
(Metric tons)

	1989	1990	1991
Iron and steel	218,000	219,200	212,300
Copper base	20,300	19,000	17,900
Aluminum	33,500	36,400	34,500
Molybdenum	2,000	2,500	2,300
Tungsten	2,100	2,500	2,100
Tungsten carbide	5,300	5,000	4,900
Nickel	10,200	10,000	9,800
Tin	1,000	1,000	825
Total*	292,400	295,600	284,625

*Estimated.

FIGURE 1

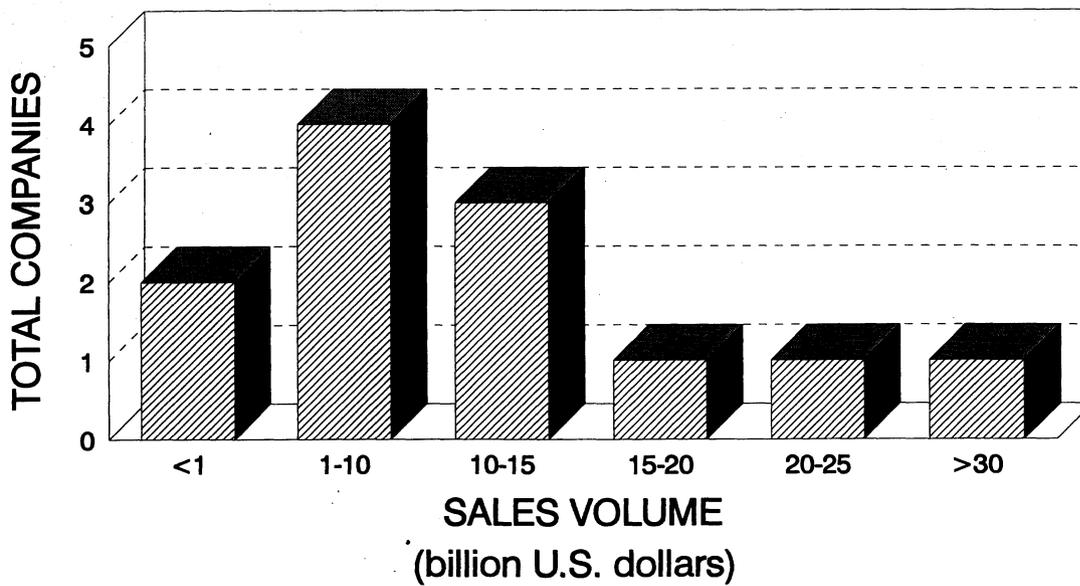
ADVANCED CERAMICS PRODUCERS, BY ANNUAL TOTAL SALES IN 1991 (United States)



Source: CorpTech.

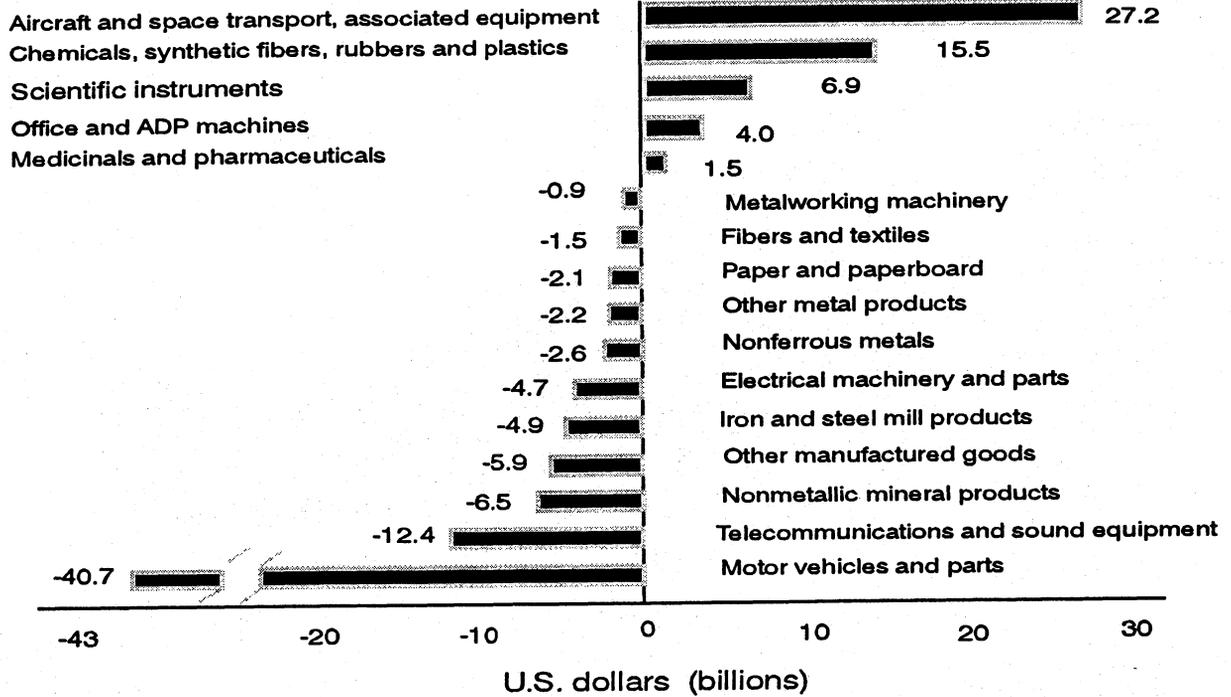
FIGURE 2

ADVANCED POLYMER COMPOSITE PRODUCERS, BY ANNUAL TOTAL SALES IN 1991 (United States)



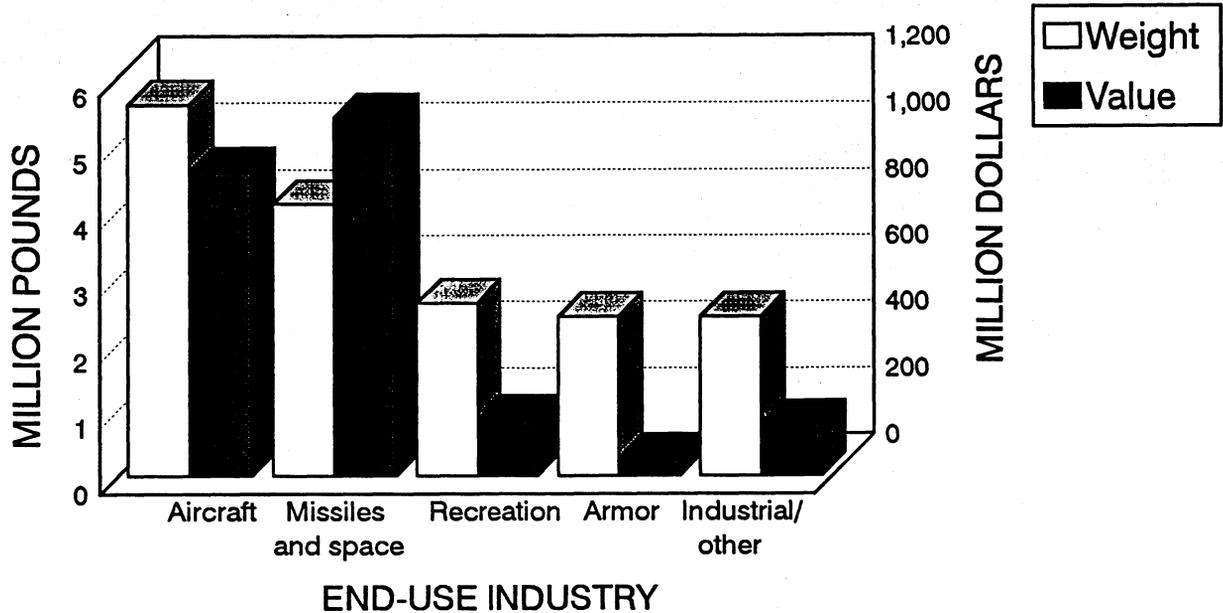
Sources: SACMA, CorpTech.

FIGURE 3
WINNERS AND LOSERS IN THE TRADE WARS, 1991



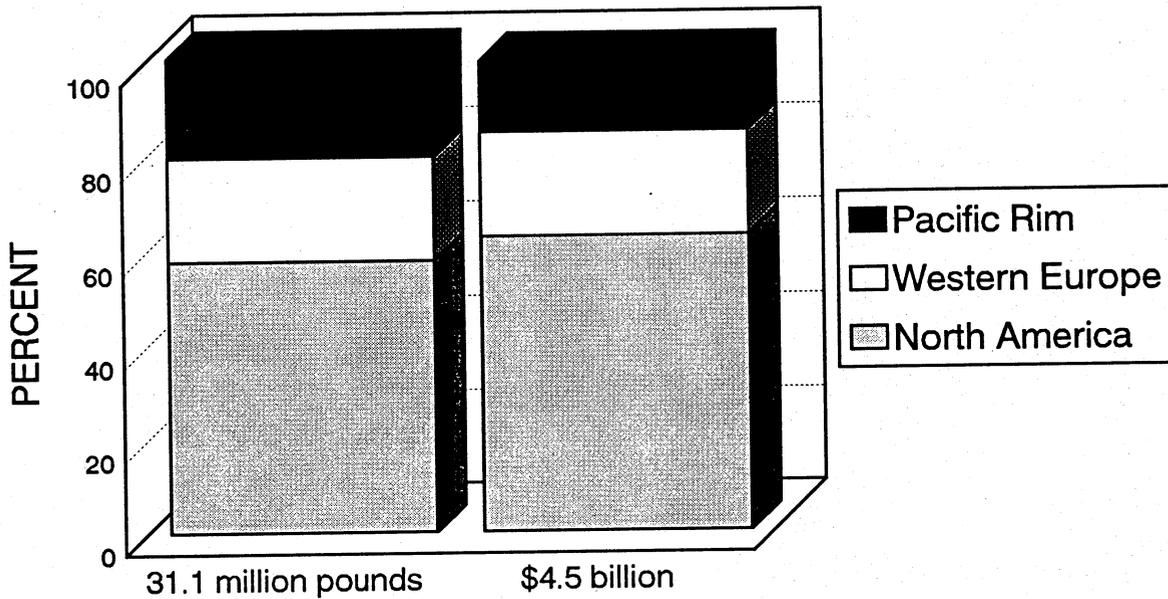
Sources: U.S. Department of Commerce and U.S. Bureau of Mines.

FIGURE 4
ESTIMATED U.S. MARKET FOR ADVANCED POLYMER COMPOSITES, BY END USE, 1991



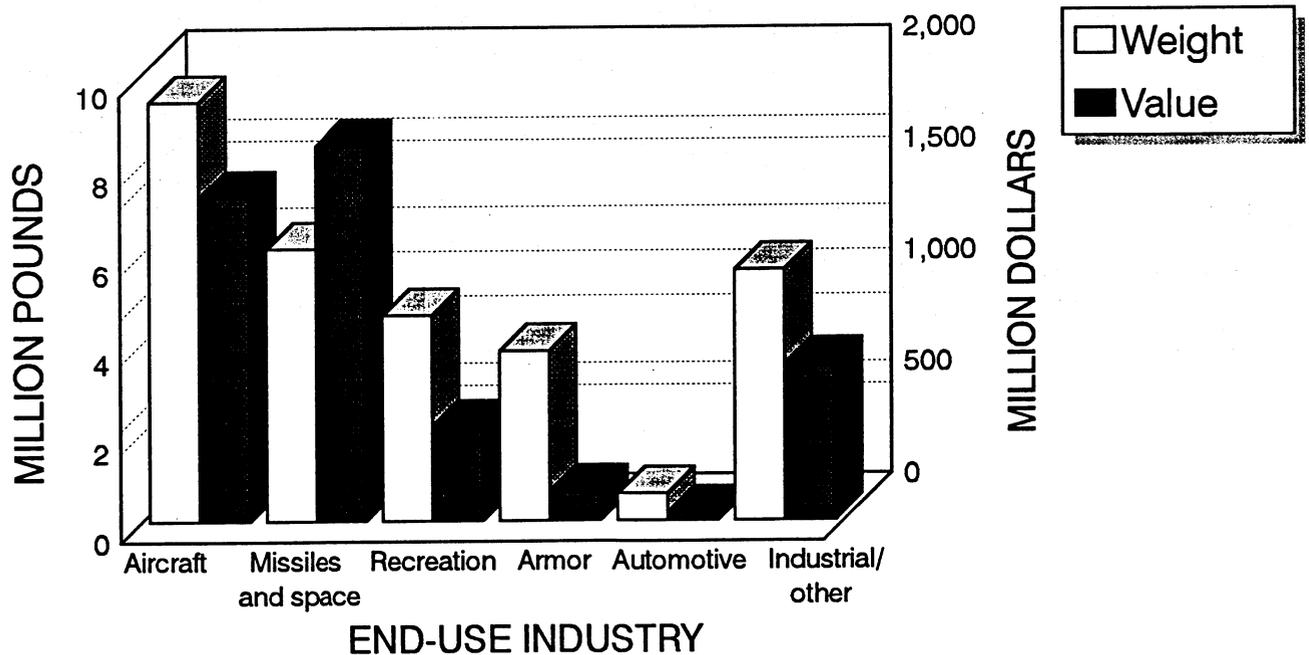
Source: Kline & Co., Inc.

FIGURE 5
ESTIMATED WORLD MARKET FOR ADVANCED POLYMER COMPOSITES, 1991



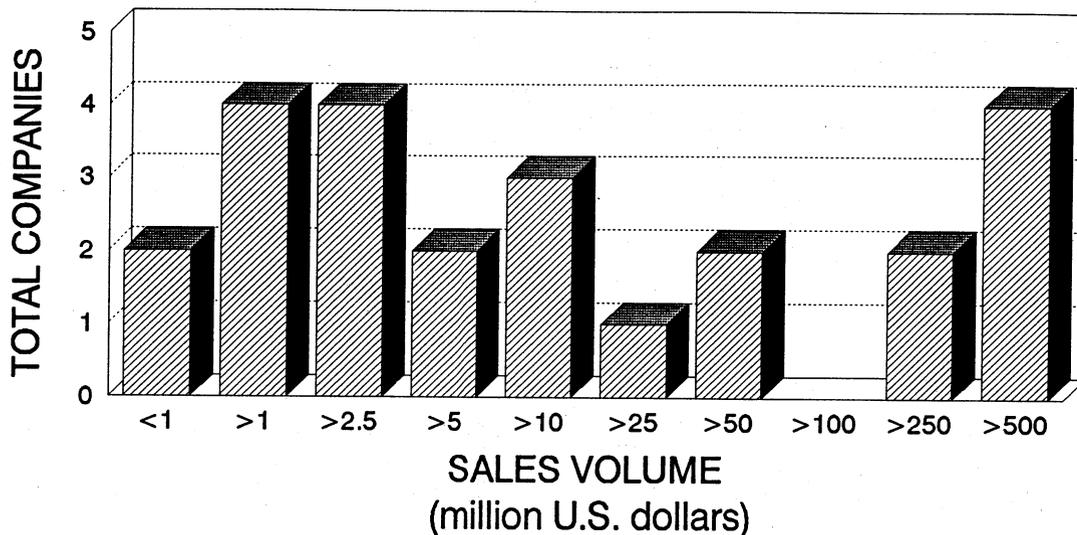
Source: Kline & Co., Inc.

FIGURE 6
ESTIMATED WORLD MARKET FOR ADVANCED POLYMER COMPOSITES, BY END USE, 1991



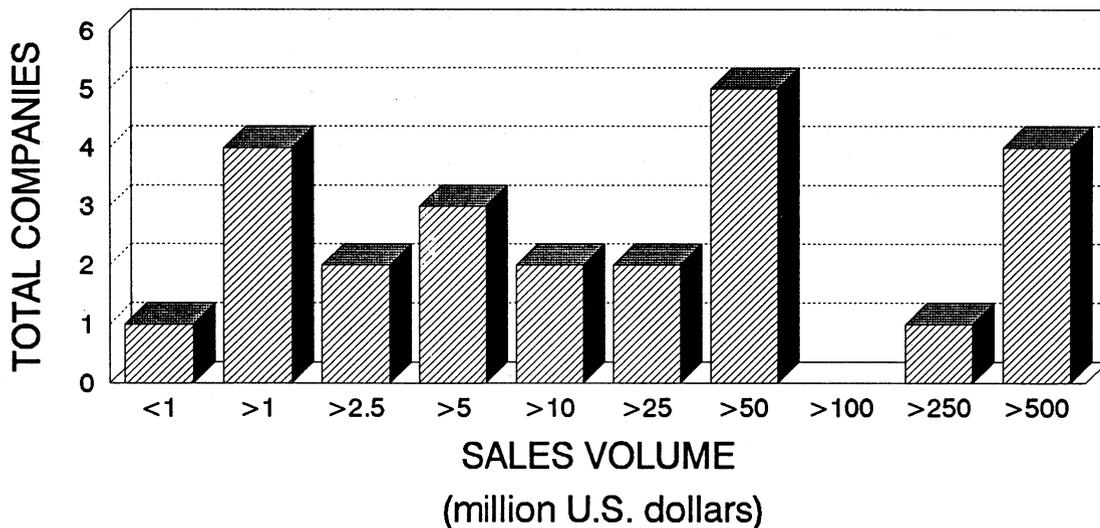
Source: Kline & Co., Inc.

**FIGURE 7
METAL MATRIX COMPOSITES PRODUCERS,
BY ANNUAL TOTAL SALES IN 1991 (UNITED STATES)**



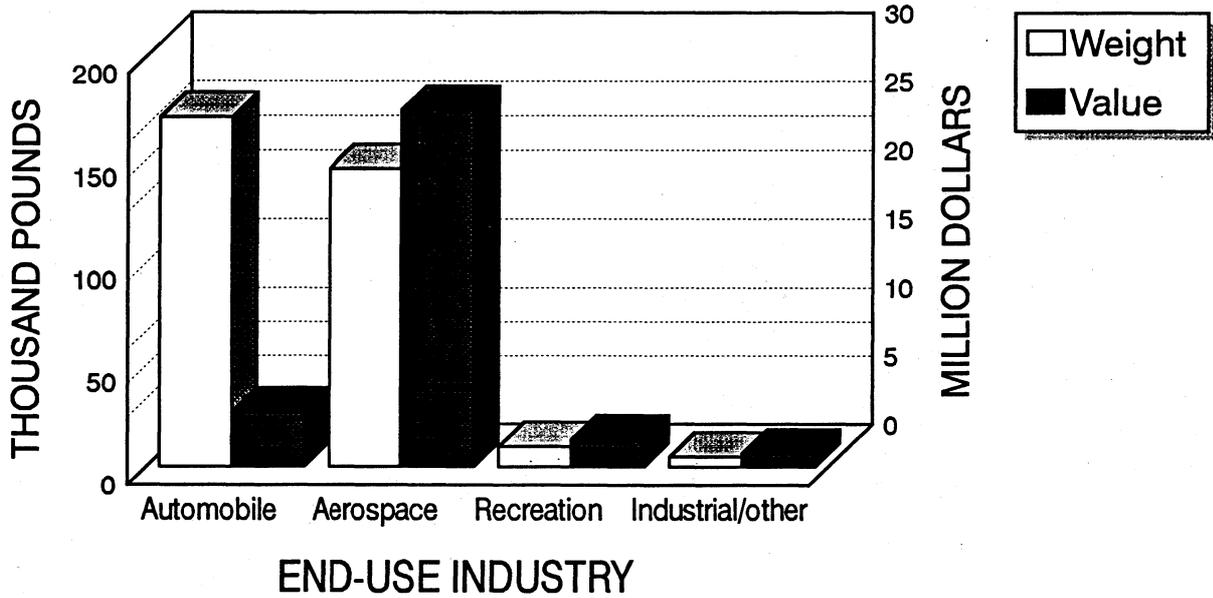
Sources: CorpTech., T. Moss, and Advanced Composites.

**FIGURE 8
CARBON-CARBON COMPOSITES PRODUCERS,
BY ANNUAL TOTAL SALES IN 1991 (UNITED STATES)**



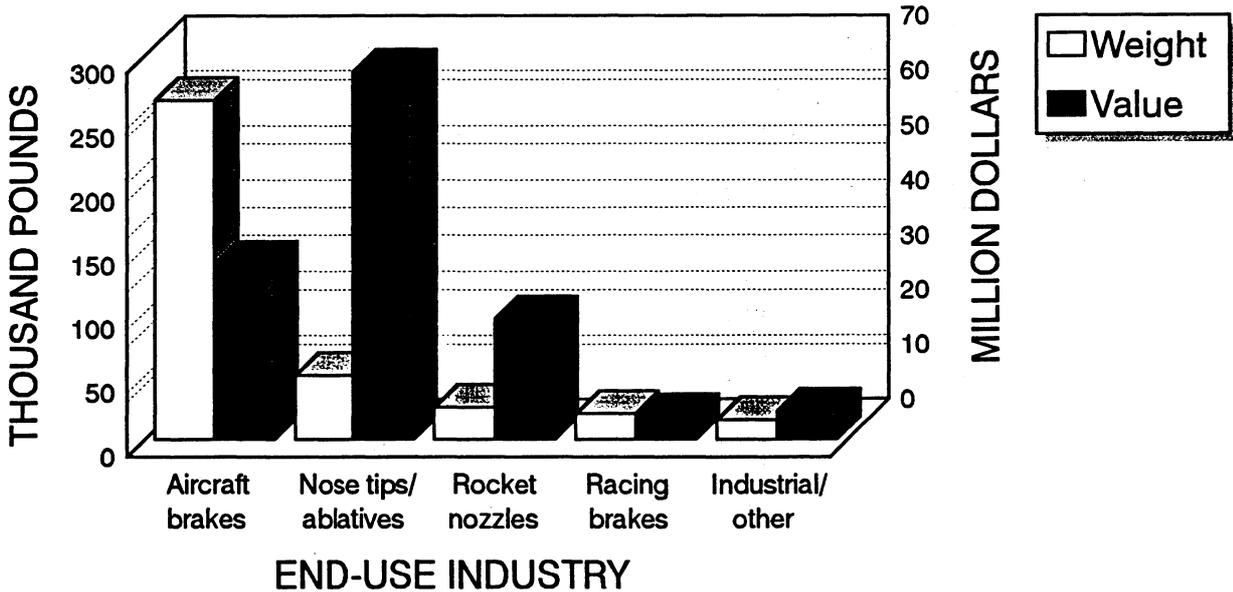
Source: CorpTech.

FIGURE 9
ESTIMATED U.S. MARKET FOR METAL MATRIX COMPOSITES,
BY END USE, 1991



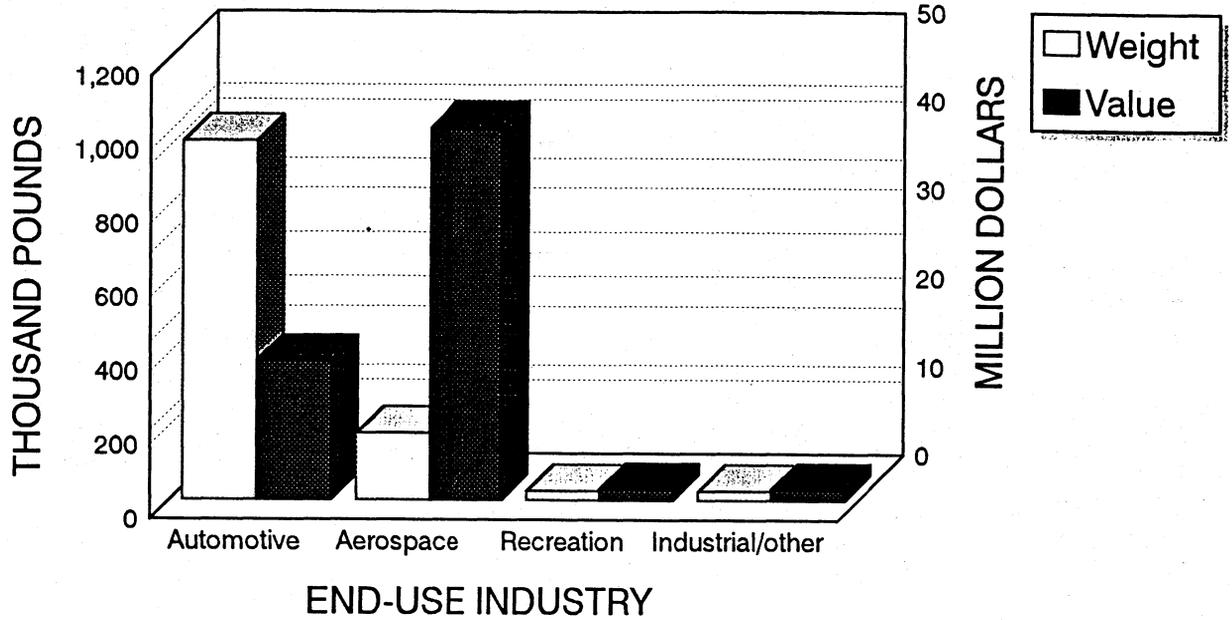
Source: Kline & Co., Inc.

FIGURE 10
ESTIMATED U.S. MARKET FOR CARBON-CARBON COMPOSITES,
BY END USE, 1991



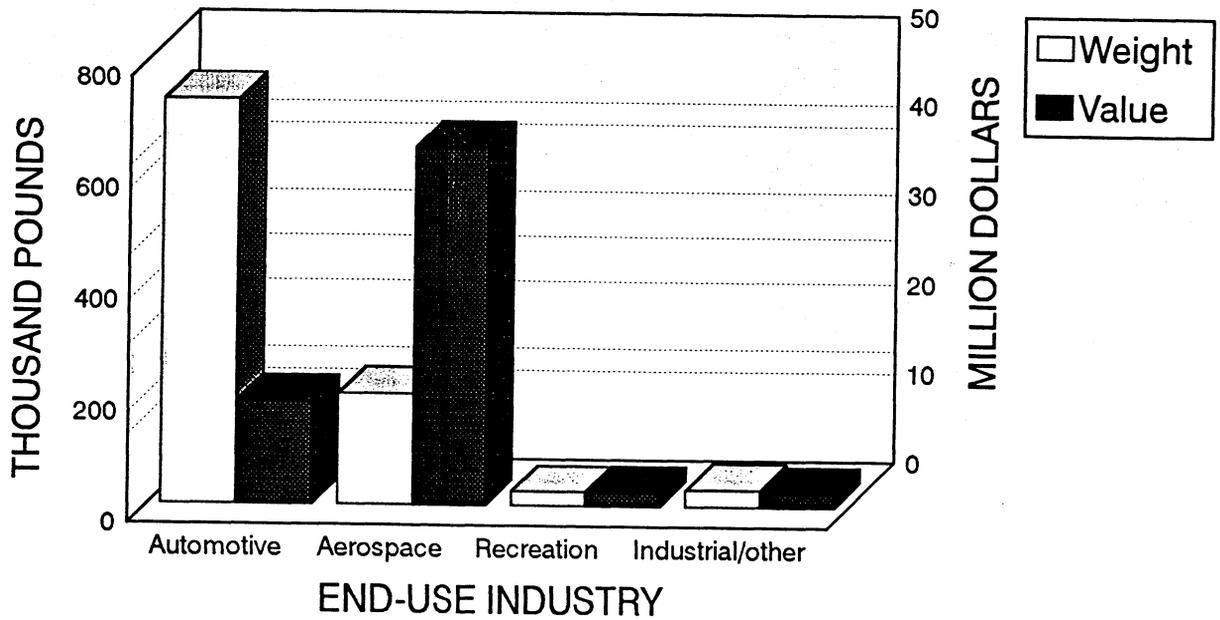
Source: Kline & Co., Inc.

FIGURE 11
ESTIMATED WORLD MARKET FOR METAL-MATRIX COMPOSITES,
BY END USE, 1990



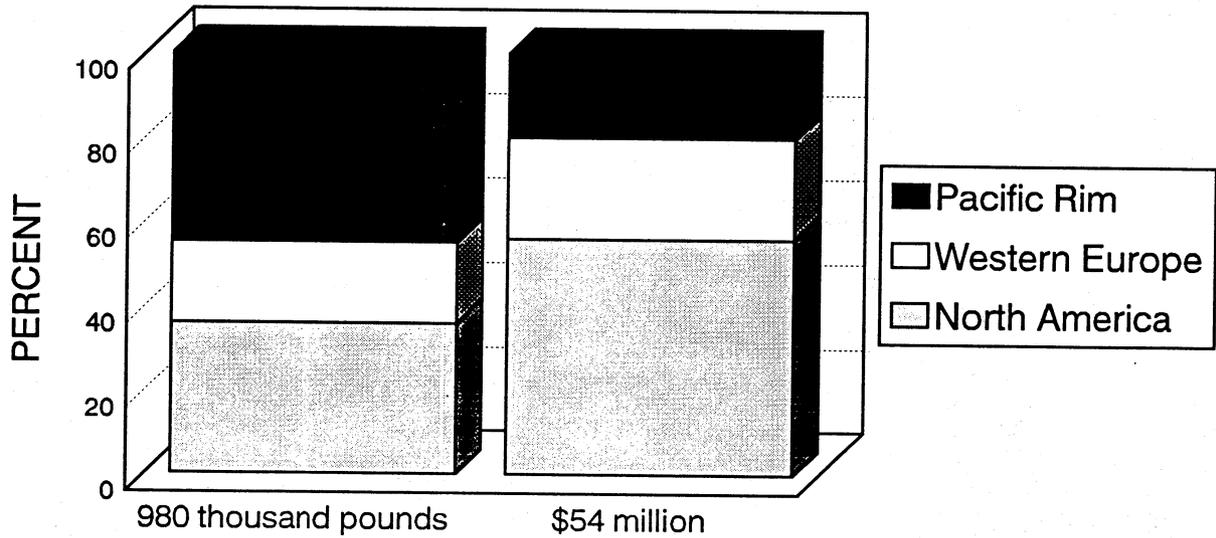
Source: Kline & Co., Inc.

FIGURE 12
ESTIMATED WORLD MARKET FOR METAL-MATRIX
COMPOSITES, BY END USE, 1991



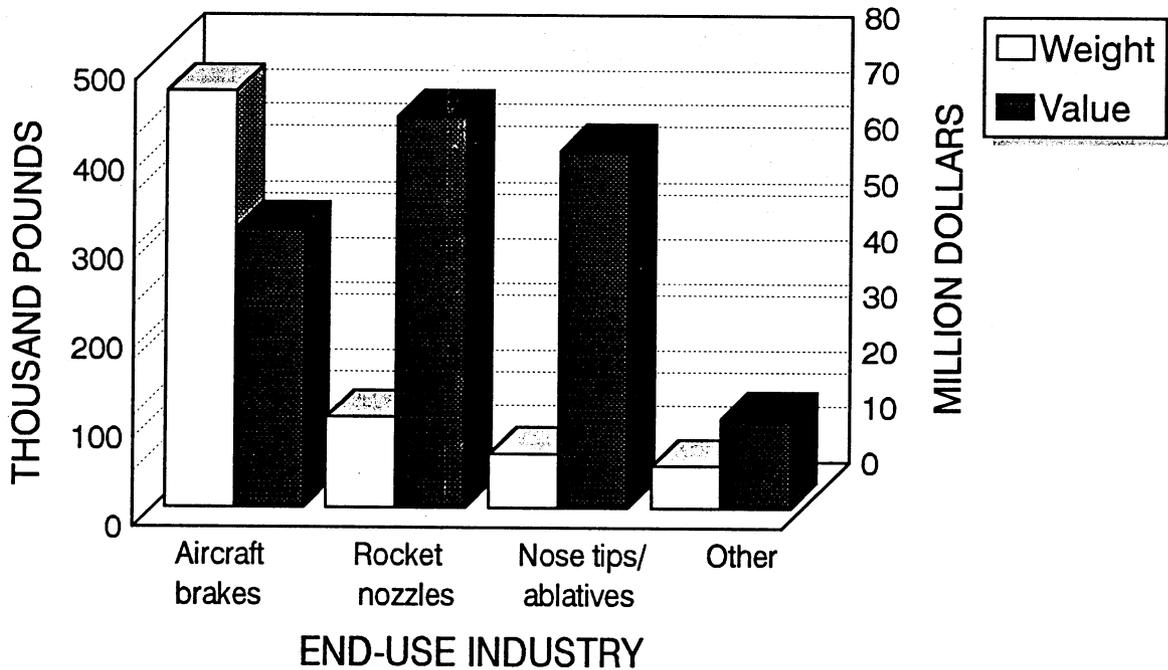
Source: Kline & Co., Inc.

FIGURE 13
ESTIMATED WORLD MARKET FOR METAL-MATRIX
COMPOSITES, 1991



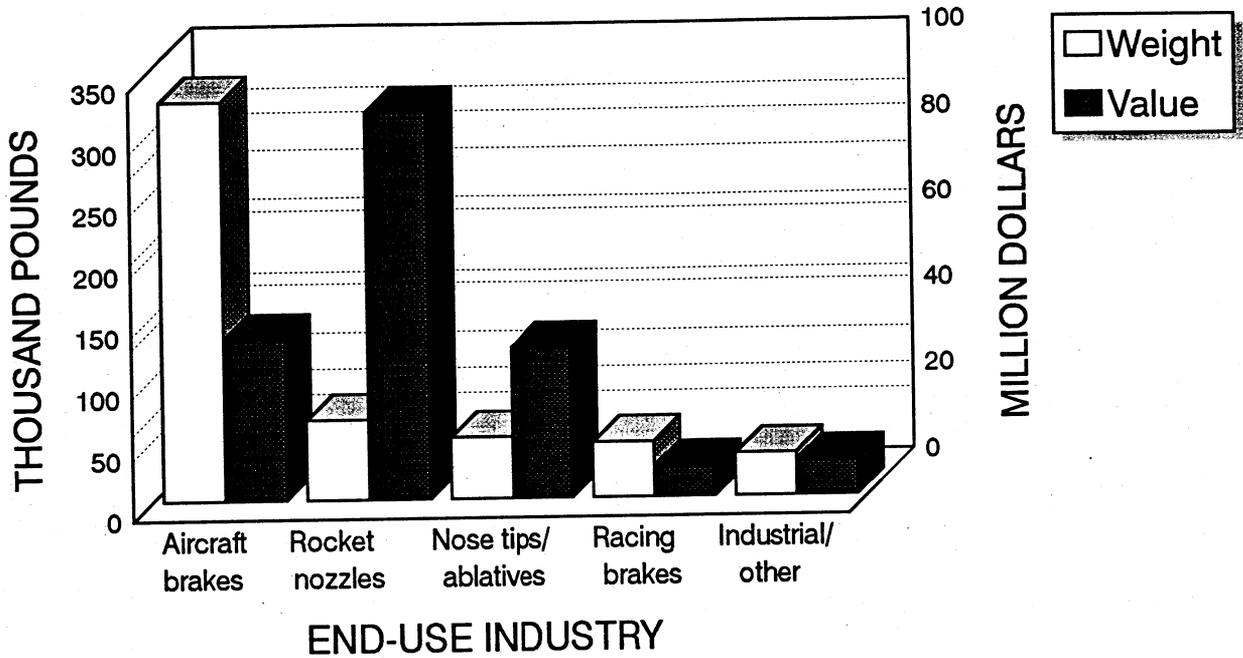
Source: Kiline & Co., Inc.

FIGURE 14
ESTIMATED WORLD MARKET FOR CARBON-CARBON
COMPOSITES, BY END USE, 1990



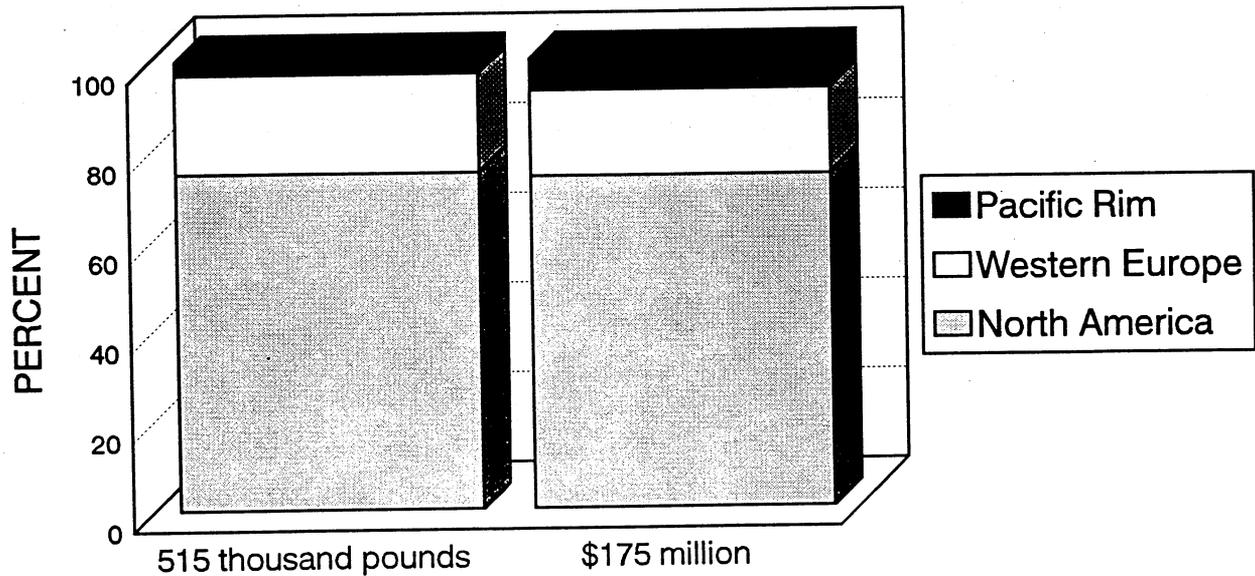
Source: Kline & Co., Inc.

FIGURE 15
ESTIMATED WORLD MARKET FOR CARBON-CARBON COMPOSITES, BY END USE, 1991



Source: Kline & Co., Inc.

FIGURE 16
ESTIMATED WORLD MARKET FOR CARBON-CARBON COMPOSITES, BY END USE, 1991



Source: Kline & Co., Inc.

ALUMINUM, BAUXITE, AND ALUMINA

By Patricia A. Plunkert and Errol D. Sehne

Ms. Plunkert, a physical scientist with 23 years U.S. Bureau of Mines experience, has been the commodity specialist for aluminum since 1987. Domestic survey data for aluminum were prepared by Shonta E. Osborne, statistical assistant; and international data tables were prepared by Audrey D. Wilkes, international data coordinator.

Mr. Sehne is a physical scientist with 18 years of minerals industry and U.S. Bureau of Mines experience. Domestic survey data for bauxite and alumina were prepared by Susan M. Copeland, statistical assistant; and international data tables were prepared by Harold D. Willis, international data coordinator, and William L. Zajac, Chief, Section of International Data.

Aluminum is the second most abundant metallic element in the Earth's crust after silicon, yet it is a comparatively new industrial metal that has been produced in commercial quantities for just over 100 years. It weighs about one-third as much as steel or copper; is malleable, ductile, and easily machined and cast; and has excellent corrosion resistance and durability. Measured either in quantity or value, aluminum's use exceeds that of any other metal except iron, and it is important in virtually all segments of the world economy.

In 1991, the aluminum market was characterized by weak demand, a high metal production level in the Western World, and increased exports from the former U.S.S.R. As a result, the price of primary aluminum metal fell throughout the year and world inventories rose, especially those held by the London Metal Exchange (LME). The United States continued to be the world leader in primary metal production, producing more than 4.1 million metric tons of metal with an estimated value of \$5.4 billion.

World production of bauxite and alumina, feedstocks for the aluminum industry, declined slightly during 1991 in response to a stagnating demand for primary aluminum metal. Mine production of bauxite was reported from 27 countries, and alumina was produced in 24 countries.

DOMESTIC DATA COVERAGE

Domestic production and consumption data for aluminum, bauxite, and alumina are developed by the U.S. Bureau of Mines from five separate, voluntary surveys of U.S. operations. Typical of these monthly, quarterly, and annual surveys is the "Aluminum" survey. Of the 13 companies canvassed by this form, all responded, representing 100% of the total domestic primary aluminum production.

BACKGROUND

Definitions, Grades, and Specifications

Bauxite is a heterogeneous material chiefly composed of the aluminum oxide minerals gibbsite [$\text{Al}(\text{OH})_3$], the trihydrate, and boehmite and diaspore (AlOOH), the monohydrates.¹ Domestic bauxites and those imported from Brazil, Guyana, and Suriname are of the trihydrate gibbsitic type. Imports from the Sangaredi deposits of Guinea and the north coast of Jamaica are predominantly gibbsitic, but they also contain 4% to 10% of the monohydrate mineral, boehmite. In most European and northern Asian bauxite deposits, boehmite is the principal alumina mineral. Recovery of the aluminum oxide in boehmite requires a higher temperature and higher caustic concentration than is

needed in processing gibbsite. Major impurities in bauxite ores include iron oxides, silica, aluminum silicates, and titanium oxides.

Free moisture in crude bauxite, as mined, may range from 5% to 30%. To produce dried bauxite, most of the free moisture is removed by heating crude bauxite in rotary drying kilns at about 315° C. Calcined bauxite is produced by heating bauxite to 925° to 1,040° C to reduce total volatile matter, including chemically combined water, to less than 1%. Approximately 2 tons of crude ore is required to produce 1 ton of calcined bauxite.

Aluminum metal has a relatively low density, high electrical and thermal conductivity, good resistance to corrosion, and good malleability. It is nonmagnetic, nonsparking, and highly reflective. It may be alloyed and treated to yield a high strength-to-weight ratio.

Ingot is a cast form of primary or secondary metal that is convenient to handle and store and is suitable for fabricating or remelting. Commercial-size ingots normally weigh about 30 pounds; however, some ingots weigh up to 9 tons. A portion of both primary and secondary metal is sold and transported in molten form.

Commercially pure aluminum usually contains about 99.7% aluminum. In the annealed condition, it has low strength and is relatively soft. However, it is available in strain-hardened conditions of

higher strength and reduced ductility. Metal with more than 99.7% and up to 99.85% aluminum is available at higher cost than standard commercial metal. Superpurity aluminum contains a minimum of 99.99% aluminum.

Aluminum alloys have been developed that, after cold rolling, heat treating, annealing, or age hardening, have strengths approaching those of mild steels. More than 100 commercial alloys are available, and several new alloys are developed each year. The alloys offer a wide variety of combinations of mechanical strength, ductility, electrical conductivity, and corrosion resistance.

Aluminum alloys are generally divided into two major groups: wrought and casting. The Aluminum Association uses a code to designate the purity and alloy content of wrought alloys and to register the composition of casting alloys and ingot.

New aluminum-base scrap, generated in the production of intermediate and end products of aluminum metal, may be pure (unalloyed), segregated (one alloy type), or mixed (two or more alloys). It includes solids, such as new casting scrap; clippings or cuttings of new sheet, rod, wire, and cable; borings and turnings from the machining of aluminum parts; and residues, drosses, skimmings, spillings, and sweepings.

New scrap is further defined as either "runaround" (home) scrap or purchased scrap. Runaround or home scrap is new scrap that is recycled by the same company that generates it; such scrap by definition never leaves the company generating it and, therefore, is never marketed as scrap. Purchased scrap is new scrap that is purchased, imported, or treated on toll by secondary smelters, the original aluminum product suppliers, or others. New aluminum scrap that is purchased from manufacturers of end products may be referred to as consumer scrap. Purchased new scrap is sometimes referred to as prompt industrial scrap.

Old scrap, all of which is considered as purchased, comes from discarded, used, and worn out products. It includes aluminum pistons or other aluminum engine or body parts from junked cars,

aluminum used beverage cans (UBC) and utensils, and old wire and cable. Sweated pig is scrap that has been sweated or melted into a pig or ingot form for convenience and economy in shipping and storage. Obsolete scrap is new, unused, but technologically obsolete aluminum end products, outdated inventory materials, production overruns, and spare parts for machines and equipment no longer being used. In the United States, both sweated pig and obsolete scrap are considered old scrap.

Geology-Resources

Bauxite is formed by the weathering of aluminum-bearing rocks under conditions conducive to the chemical breakdown of minerals within the parent rock. In the weathering process, the aluminum is retained as hydrated aluminum oxide minerals and other constituents are leached from the parent rock. Conditions favorable for the formation of bauxite existed in areas and geological periods that provided warm wet climates, aluminous parent rocks with high permeability and readily soluble minerals, good subsurface drainage, and long periods of tectonic stability that permitted deep weathering and preservation of land surfaces.

Major bauxite deposits that supported the U.S. aluminum industry for almost 100 years were formed in central Arkansas by weathering of nepheline syenite intrusives during late Paleocene and early Eocene time.² The predominant aluminum oxide mineral that occurred within these now-depleted bauxite deposits was the trihydrate form, gibbsite. Some deposits were residual on the igneous rock and clay, while others were the result of transportation and accumulation of eroded deposits. Most of the deposits were subsequently covered by sand and clay beds. Bauxite ore ranged in thickness from a few feet to 65 feet and was overlain by a 40- to 150-foot layer of overburden. The composition of the ore mined in the Arkansas region varied widely within a range of 40% to 52% Al_2O_3 , 7% to 17% SiO_2 , and 6% to 12% Fe_2O_3 . Permanent closure of the

last remaining bauxite mining operations in Arkansas occurred in 1990.

The bauxite deposits currently mined throughout the coastal plain of Alabama and Georgia are found as lenses within flat-lying beds of kaolinitic clay, which are overlain by sand and clays of early Tertiary age. Average ore thickness is 10 feet, though locally 33-foot ore thicknesses have been encountered. Overburden, especially in the Alabama sinkhole deposits, can exceed 120 feet in thickness. The grade of the bauxite is 48% to 56% Al_2O_3 , 12% to 16% SiO_2 , and less than 2.5% Fe_2O_3 . The low iron oxide content permits this ore to be used in refractory and chemical applications. These specialty products often incorporate a natural mixture of bauxite and bauxitic kaolin.

In Jamaica, the bauxite deposits fill sinkholes and channels and blanket uneven depressions in the karst surface of a limestone of middle Tertiary age. Individual ore bodies range from pockets containing a few hundred tons of bauxite to basins containing millions of tons. The soil overburden is only 1 to 2 feet thick. Jamaican bauxite is largely gibbsitic, although mixtures containing up to 20% monohydrate alumina occur in some ores. Ore grade is 45% to 49% Al_2O_3 , 0.8% to 8% SiO_2 , 17% to 22% Fe_2O_3 , and 2.5% TiO_2 . The bauxite deposits in the Dominican Republic and Haiti are similar in grade, age, and genesis and are identified as "Jamaica-type" bauxites.

Bauxite deposits in Guyana and Suriname are scattered throughout a narrow belt extending along the contact between the Precambrian crystalline rocks of the Guyana Shield and the sedimentary beds of Tertiary or later age that form the coastal plain. These deposits usually rest on kaolinitic clay and range from exposed outcrops to ore bodies overlain by as much as 200 feet of sand and clay, although the average overburden is about 60 feet. Other deposits of bauxite and laterite occur in these countries at higher elevations south of the coastal belt. The alumina mineral is gibbsite and the ore is high grade; typically 55% to 60% Al_2O_3 , 2% to 5% SiO_2 , and less than 3% Fe_2O_3 .

Both countries have been exporters of refractory- and abrasive-grade bauxite.

In the large deposits discovered within northern Brazil since 1967, the bauxite occurs as a residual capping on dissected plateaus several hundred feet above the Amazon or other nearby rivers. The ore has developed on unconsolidated Tertiary sediments and is covered by 12 to 30 feet of kaolinitic clay. Ore thickness averages about 16 feet. The approximate grade after washing is 55% Al_2O_3 , 3.5% SiO_2 , and 11% Fe_2O_3 . Bauxites in northern Brazil and Venezuela are of the gibbsitic type and contain little monohydrate alumina.

The Weipa bauxite deposit in Queensland, Australia, occurs in the upper portion of a flat-lying laterite that extends for more than 100 miles along the west coast of the Cape York Peninsula. The bauxite ranges in thickness from a few feet to 30 feet and is covered by a soil overburden 1 to 3 feet thick. Average ore thickness is about 14 feet. The ore is basically gibbsitic, but some of the alumina is also present in the form of boehmite. The deposits are associated with Tertiary kaolinitic sands, from which they were probably derived. The grade of the beneficiated bauxite is 53% to 58% Al_2O_3 , 4% to 7% SiO_2 , and 12% Fe_2O_3 .

The Darling Range bauxite deposits in Western Australia occur as a residual capping on Precambrian granites, gneiss, and intrusive crystalline rocks. A thin, 1.5-foot blanket of soil mixed with loose pisolites covers the deposits. The top of the ore is characterized by a ferruginous hardcap about 6 feet in thickness. The deposits are characterized by a low alumina and a high quartz sand content; however, the reactive silica is typically less than 2%. General composition is 38% to 46% Al_2O_3 , 10% to 23% SiO_2 , 11% to 16% Fe_2O_3 , and about 4% TiO_2 .

In Guinea, the large Sangaredi bauxite deposits occur as laterite caps on inland plateaus at elevations of 900 feet or more above sea level. The deposits have been dissected by stream drainage systems. Most of the bauxite is believed to have formed through weathering of schists and sandstones of Devonian or post-Devonian

age. The thickness of the Sangaredi bauxite ore averages more than 65 feet and exceeds 130 feet in some places. Overburden, where present, consists of a thin topsoil. Typical ore contains 57% to 60% Al_2O_3 , less than 1% SiO_2 , and 2% to 4% Fe_2O_3 . The upper zone of the Sangaredi deposit contained only a few percent boehmite, but mining has progressed to lower benches where the monohydrate content has increased to almost 10%. To extend the overall life of the mining project, operations are currently being expanded to the adjacent Bidikoum ore body.

Many of the European bauxite deposits are associated with pockets and depressions in the karst weathering surface of Mesozoic limestone beds that have been buried, folded, and faulted subsequent to the development of the bauxite. European bauxites are composed predominantly of monohydrate alumina minerals, although some gibbsitic deposits are mined in Hungary and a few other countries.

In the past, the commercial production of primary aluminum has been based almost entirely on the use of bauxite. However, deposits containing aluminum in the other mineral forms are widespread and virtually inexhaustible. The average aluminum content of the Earth's crust has been estimated at 8.3% (15.7% on an Al_2O_3 basis), and deposits containing more than 13% aluminum (25% Al_2O_3) are common.

Information on bauxite reserves and resources varies from reports based on thorough exploration for some deposits to reports giving only a total quantity estimate based on unspecified fieldwork for other deposits. The reserve and reserve-base estimates in table 3 are the result of evaluating data and information obtained from many sources. The quality of bauxite deposits cannot be assessed by the alumina content alone because the mineralogical form in which the alumina occurs; its extractability in the Bayer process; the quantity of reactive silica present; iron content, including the ratio of ferric to ferrous iron; and other chemical and physical properties all affect the process cost and the alumina

recoverable from a given bauxite. The classification of undeveloped bauxite deposits as either reserves or subeconomic resources also is a matter of judgment because many factors other than grade influence the economics of mining, transporting, and processing the bauxite to alumina. The definitions of reserves and reserve base are published in U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals."³

Past estimates of world bauxite reserves were about 1 billion metric tons in 1945, almost 3 billion tons in 1955, 6 billion tons in 1965, and about 21 billion tons in 1985. In 1991, they were estimated at approximately 23 billion tons. Guinea and Australia together possess nearly one-half of the world's known reserves. More than 25% occurs in the Western Hemisphere, principally in Brazil, Jamaica, Guyana, and Suriname. Estimates of additional bauxite classified as subeconomic, hypothetical, or speculative resources bring the total world resources of bauxite to within the range of 55 to 75 billion tons. Growth in reserves has roughly paralleled the expansion of world bauxite production capacity. Major new discoveries are the primary factor in reserve increases; however, production economies resulting from technological advances and large-scale operations have also permitted the inclusion of lower grade bauxite previously considered subeconomic.

Historically, the principal domestic sources of bauxite were in central Arkansas, where reserves were estimated to have been about 15 million metric tons prior to the permanent closure of the last mining operations in 1990. An additional 2 to 5 million tons of bauxite reserves in Alabama and Georgia are the principal source of domestic refractory and chemical bauxites.

The resources of bauxite in the United States, other than the present reserves, are chiefly in (1) large low-grade deposits containing substantial quantities of clay minerals in Arkansas, Alabama, and Georgia; (2) ferruginous bauxite deposits in Oregon and Washington; and (3) deposits of low-grade ferruginous bauxite

in soils and weathered basalts on Kauai and Maui, Hawaii. Inclusion of these low-grade resources increases the total estimated bauxitic resource in the United States to 290 to 315 million tons. The mining of some of these deposits may be restricted or prohibited because of environmental considerations such as their proximity to populated or scenic areas.

Nonbauxitic aluminum-bearing deposits in the United States that have received the most attention as potentially economic sources of aluminum include kaolinitic clays, anorthosite, and alunite. Other types of clays, shales, schists, nepheline syenite, and saprolite are also potential aluminum raw materials. In addition, the production of certain other mineral products yields aluminous materials that may be considered potential sources of metal. These include coal ash and coal mining refuse, copper leach solutions, aluminum phosphate rock, and dawsonite produced in conjunction with the mining of oil shales. (See tables 1, 2, and 3.)

Technology

Exploration.—The first stage of planning a bauxite exploration program usually entails a thorough study of regional geology, physiography, and any previous reports on exploration or mining operations within the area of interest. The initial regional appraisal should include a review of topographic maps (rarely available for remote tropical areas), aerial photographs, satellite imagery, and mosaics prepared from aerial side-looking radar (SLR) surveys. In the Amazon Basin of Brazil, where the dense rain forest canopy completely masks stream valleys, scarps, and plateaus, SLR methods have proven effective in revealing the hidden topography. Geobotanical techniques using true- or false-color air photos and satellite images have been used to identify vegetation types associated with aluminous laterites. Airborne radiometric surveys are useful in delineating exposed laterites by their typically elevated levels of radioactivity.

After specific target areas have been defined, reconnaissance by helicopter or fixed-wing aircraft can provide valuable accessibility and logistical support information. Surface prospecting for float samples in river drainage systems has long been a reliable guide in the discovery of bauxite deposits. Vertical channel sampling of indurated resistant outcrops exposed in stream valleys can often provide the first positive identification of the presence of bauxite. Detailed evaluation and development require drilling, pitting, or trenching to provide samples for chemical analysis. Surface mapping is essential to document drill collar and test pit locations and elevations.

Bauxite minerals are difficult to identify visually and require sophisticated laboratory techniques for quantitative analysis. Because of this requirement, exploration samples and development samples are often shipped to a major chemical laboratory for analysis. The most significant determinations are for alumina and silica content. Both "total alumina" and "available alumina" (alumina recoverable by both low- and high-temperature Bayer processes) are normally determined. In addition to "total silica," it is important to analyze for "reactive silica" because the latter combines with alumina and soda in the Bayer process to form sodium aluminum silicates that are lost in the red mud wastes. Iron oxides, titania, and loss on ignition are also routinely determined.

Mining.—Open pit mining has accounted for all of the bauxite mined in the United States in recent years and for approximately 95% of the world bauxite production. Restoration of the land surface at depleted bauxite mines is being accomplished in many parts of the world by preserving the topsoil stripped from the mine sites for later replacement on the reclaimed areas.

Before the closure of mining operations in Arkansas, draglines, scrapers, shovels, and trucks were used in the stripping of overburden. Stripping ratios as high as 13 feet of overburden to 1 foot of ore were utilized, and some surface pits in

Arkansas reached depths of approximately 200 feet. The pit walls of unconsolidated sand and clay were relatively stable; however, some slumping did occur. In the earlier phases of the mining operations, flat-lying ore was recovered by room-and-pillar mining along a retreating line of controlled rock collapse. Underground bauxite mining ceased in Arkansas in 1976, and the remaining surface mining operations were closed in 1990.

Surface mining methods and a similar mix of equipment are presently employed at the nonmetallurgical bauxite mining operations in the Eufaula district of Alabama and Andersonville district of Georgia.

In Jamaica, the bauxite deposits lie closer to the surface, and the overburden of vegetation and topsoil is easily stripped. The ore usually requires no blasting. Shovels, draglines, and scrapers are used to load the ore. Haulage is by truck, railroad, or aerial tramline to the alumina plants and port facilities. In Suriname and Guyana, up to 200 feet of overburden is stripped by draglines, scrapers, bucket wheel excavators, or hydraulicking. The ore is broken by blasting and loaded into ore cars or trucks with power shovels, backhoes, or draglines.

At Weipa, Australia, bulldozers and scraper loaders remove the few feet of overburden. Front-end loaders, each mining in excess of 500 tons per hour, then load the uncemented pisolitic ore into trucks for a relatively short haul to a beneficiating plant for sizing and washing. At the deposits in the Darling Range of Western Australia, forest clearing of vegetation and overburden removal are followed by blasting of the hardcap that comprises the top few feet of the bauxite deposits. Front-end loaders load dump trucks for haulage to a mobile crushing plant. Bauxite is carried from the crusher to an alumina plant by conveyer belt.

The Sangaredi deposits mined for the Boké project in Guinea have little overburden but require blasting. Loosened ore is loaded by electric shovels directly onto railcars for shipment

85 miles to the Kamsar treatment (drying and calcining) facility and port site.

Underground mining accounts for much of the current Greek and Hungarian bauxite production and is also employed in other parts of Europe, including the U.S.S.R. Room-and-pillar and various stoping methods are used. Underground water problems are common—especially in the Hungarian mines, where bauxite deposits are associated with the weathering of limestone. Here dewatering of underground workings has accounted for 10% to 15% of the mining cost.

Beneficiation.—Bauxite treatment is usually confined to crushing, washing, and drying operations. Most of the bauxites that are mined do not require the more costly beneficiation techniques used on some other metal ores. Moreover, most impurities such as iron, silicon, and titanium are frequently so finely dispersed in the bauxite that they cannot be readily separated by physical methods. Many bauxites are upgraded, however, by washing or wet screening to remove sand and some of the clay minerals (reactive silica).

Metallurgical and chemical grades of bauxite that must be transported appreciable distances are normally dried before shipment. Drying facilitates the handling of some bauxites, and the degree to which a specific bauxite is dried depends in part on its handling and dusting characteristics. Because crude bauxite may contain 10% to 30% free moisture, drying results in savings in freight charges that may more than offset drying costs. Bauxite from Guinea usually is dried to 3% to 6% moisture, whereas Jamaican bauxite is shipped with about 15% moisture. Bauxite for use in refractories and abrasives is calcined to remove both free moisture and chemically combined water.

Alumina Production.—Virtually all alumina produced commercially from bauxite is obtained by a process patented by Karl Bayer in 1888 (German Patent 43,977), although research on aluminum extraction from other mineral raw

materials has continued for many years. The Bayer process involves a caustic leach of the bauxite at elevated temperature and pressure, followed by separation of the resulting sodium aluminate solution and selective precipitation of the aluminum as the hydrated aluminum oxide [$\text{Al}(\text{OH})_3$].

The actual processing conditions such as the leach temperature, holding time, and caustic concentration, as well as the costs, are influenced by the type of bauxite to be processed. As a result, a Bayer alumina plant is designed to treat a specific type of ore and, in general, cannot use a bauxite that is markedly different from the one the plant was originally designed to use without major plant modifications. The Bayer process is initiated by mixing crude bauxite with preheated spent leach solution. Lime is added during this initial step to control the phosphorus content and to increase the solubility of alumina within the plant feed. The resulting slurry, containing 40% to 50% solids, is pumped with additional caustic leach solution to pressurized digesters where high-pressure steam is used to raise the temperature. Alumina and some of the silica are dissolved during this step, soluble sodium aluminate is formed, and a complex sodium aluminum silicate is precipitated from the process stream.

Digestion, in tanks 10 to 15 feet in diameter and up to 90 feet high, takes up to 5 hours. Leaching temperatures range from about 105° C to about 290° C, with corresponding pressures ranging from about 60 pounds per square inch (psi) to more than 1,000 psi. The lower temperature ranges are used for bauxites in which nearly all of the available alumina is present as gibbsite. The higher temperatures are needed to digest bauxites having a large percentage of boehmite. Caustic concentration of the spent leach solution, expressed as grams per liter of sodium carbonate (Na_2CO_3), averages about 200 grams per liter for gibbsitic bauxite and about 300 grams per liter for bauxites with a high boehmite content.

The resulting slurry of sodium aluminate solution and insoluble red mud from the digesters is cooled to

atmospheric boiling temperature, and a coarse sand waste fraction is removed by gravity separators or wet cyclones. The fine solids in the red mud are then separated by decantation of the overflow in settling tanks measuring about 15 feet in depth and 50 to 125 feet in diameter. A flocculant such as starch is added to increase the settling rate of the red mud particles. The overflow from the settling tanks containing the alumina in solution is clarified by filtration and placed into precipitating tanks ranging in size from 25 to 30 feet in diameter and up to 80 feet in height.

The clarified sodium aluminate liquor is cooled until it becomes supersaturated, then seeded with fine crystals of alumina trihydrate. The alumina is precipitated as the trihydrate, separated by sedimentation or filtration, and washed. The spent leach solution containing caustic soda is regenerated in the precipitation step, and together with the alumina remaining in solution, is recycled to the digesters. The filtered and washed alumina trihydrate is calcined for use in making aluminum metal. A portion of the washed alumina may be left in the trihydrate form for chemical uses or it may be further processed under controlled conditions to produce a variety of chemical aluminas, such as activated or tabular alumina for uses other than metal production.

Two forms of calcined alumina are used to produce aluminum. European Bayer plants have traditionally produced a fine-grained, highly calcined, flourey alumina while North American Bayer plants have always produced a coarser grained, porous, sandy alumina that has not been totally calcined to the alpha alumina stage (artificial corundum). The relatively large surface area of the sandy alumina particles compared with the flourey alumina particles permits their use as an absorbent in dry scrubber units at primary aluminum smelters. Fluorine in the gases emitted from the smelter's potlines is trapped by the alumina and is later recycled when this sandy alumina is used as feed for metal production in the facility's reduction cells. Pressure from environmental regulations and improved economics through recovery of fluorine

have been important factors in the conversion of world alumina plants to produce a sandy rather than a floury alumina product.

The red mud waste stream contains Fe_2O_3 , TiO_2 , the sodium aluminum silicate complex, and small quantities of other metal oxides. Because the insoluble sodium aluminum silicate complex represents a loss of both alumina and soda, a low reactive silica content in the bauxite is desirable. Reactive silica contents of more than 8% are usually uneconomic for treatment by the Bayer process because approximately 1.1 units (weight unit) of alumina and 1.2 units of soda are lost for each unit of reactive silica in the ore. The loss of soda is made up by adding caustic soda or soda ash and lime to the spent leach solution to bring it up to the appropriate caustic concentration before it is recycled.

Bauxite with 8% to 15% silica may be treated by the combination Bayer-sinter process developed by the Aluminum Co. of America (Alcoa). In this process, the bauxite is first subjected to a Bayer leach. The resulting red mud, containing sodium aluminum silicate, is sintered with limestone and soda ash and then leached with water to recover alumina and soda. Alumina produced by this combination process is of relatively high purity and commands a premium price. The insoluble residue (brown mud) resulting from leaching the sintered materials has a composition somewhat similar to that of portland cement.

The upper limit of silica for use in the combination Bayer-sinter process is about 15%. However, in practice, bauxite containing some clay and as much as 25% silica has been mined and blended with low-silica ore in proportions that gave a feedstock of approximately 12% to 13% silica. At present, variations of the combination process are reportedly used by plants in China and the U.S.S.R.

In the U.S.S.R., alumina has been extracted from nepheline $[(\text{Na},\text{K})\text{AlSiO}_4]$ flotation concentrates and other nonbauxitic materials containing about 30% alumina. Nepheline syenite has been mined at Belogorsk in Siberia and obtained as a byproduct of apatite

recovery from syenite deposits in the Kola Peninsula. The process employed involves sintering the nepheline with lime followed by leaching. Alumina reportedly has also been produced from alunite $[\text{KAl}_3(\text{OH})_6(\text{SO}_4)_2]$ in the Azerbaijan region.

In the past, a small tonnage of alumina has been commercially extracted in Norway from high-iron bauxites by the Pedersen process. In this process, bauxite, limestone, coke, and iron ore were smelted in an electric furnace to produce pig iron and calcium aluminate slag containing 30% to 50% alumina. The slag was leached with sodium carbonate solution, and alumina trihydrate was then precipitated by carbon dioxide. During World War II, the process was also used at a Swedish plant to treat andalusite (Al_2SiO_5).

Smelting.—Primary Aluminum Production.—Primary aluminum is produced by the reduction of alumina by electrolysis in a molten bath of natural or synthetic cryolite (Na_3AlF_6), which serves as an electrolyte and as a solvent for the alumina. The reduction cells or pots containing the bath are about 10 to 15 feet wide, 20 to 40 feet long, and about 3 to 4 feet deep, lined with carbon, and connected in electrical series of 100 to 240 cells to form a potline. From 800 to 3,000 pounds of aluminum is produced per day in each pot. The carbon lining is in contact with the molten aluminum metal and serves as the cathode. It usually must be replaced after 3 to 4 years.

Cryolite and aluminum fluoride are added to the electrolyte to maintain the desirable ratio of sodium and aluminum fluoride and to replace fluorine lost from the cell in pot linings or through volatilization. The melting point of the bath is lowered by the addition of small quantities of fluorspar or, in some instances, lithium compounds. The carbon anode, which is consumed during the operation, is replaced using the Soderberg continuous method or the prebaked method.

In the Soderberg method, a reinforced rectangular steel shell, approximately 3 to

5 feet high and open at the top and bottom, is suspended above the furnace. The carbon mass of paste or briquets of coke and pitch within the shell forms the anode and is added periodically as the anode is consumed. Current enters the anode through rows of pins inserted into the carbon mass either vertically or horizontally. The heat of the bath and the heat resulting from the electrical resistance of the carbon bake the anode mass so that it becomes a hard monolithic mass from the surface of the electrolyte to a point approximately 20 inches above the bath. As the carbon anode is consumed and additional carbon descends through the rectangular steel shell and is consumed, the lowest pins are withdrawn and replaced at higher levels in the carbon mass. The optimum anode-cathode distance is maintained by raising or lowering the pins, which become baked into the lower part of the carbon block.

In the prebaked anode system, sets of 16 to 24 prebaked carbon blocks are used for the anode. The size of the blocks varies from plant to plant; typical blocks are about 20 inches wide, about 30 inches long, and 12 to 18 inches high. They weigh 400 to 600 pounds. Steel stubs or rods, which suspend the block in the bath and conduct the current to the carbon, are sealed in the anode block by pouring molten iron around the rod and allowing it to solidify. The blocks are raised or lowered separately to maintain proper position with respect to the bath and are replaced individually as they are consumed.

The Soderberg system requires less labor and, except for moving the steel pins, is a continuous method of feeding anode carbon. The prebaked system results in better electrical efficiency in the reduction cell but requires separate anode fabricating and rodding facilities not required in the Soderberg system. The prebaked system permits efficient collection of the cell offgases for subsequent treatment to remove fluorine; the off gases from a Soderberg cell are difficult to collect, necessitating fluorine recovery from a larger volume of gas than that generated in prebaked systems.

The molten bath or electrolyte may be as deep as 14 inches, but the anode is usually only 2 inches from the pad of molten aluminum collecting on the carbon cathode. The optimum operating temperature is between 950° to 985° C. At this temperature range, the alumina content of the bath ranges from 3% to 10%. When the alumina concentration drops to about 2%, the electrical resistance of the cell increases sharply, chiefly because of a gas film that envelops the anode, and the voltage drop across the cell increases from 5 volts to 30 to 40 volts. The phenomenon is known as the "anode effect," and as soon as it occurs, the crust of frozen cryolite on top of the bath is broken and more alumina is added to the cell, which then returns to normal operating condition.

Every 1 or 2 days the molten aluminum is removed from the bottom of the cell by a vacuum siphon technique. Thermally insulated cast-iron pots with airtight lids and downward-sloping spouts are used to withdraw the molten metal. The pot is evacuated, and the molten metal is sucked into the cast-iron pot. The molten metal is blended in a holding furnace with other batches and alloyed and cast into various solid forms or transported molten to fabricating plants as far as 300 miles away.

Utilizing direct current, cells operate at 65,000 to 150,000 amperes; the majority of plants have 80,000- to 100,000-ampere cells. Anode current densities range from 600 to 800 amperes per square foot. The voltage drop across a single cell is 4.5 to 5.0 volts; across a potline, it may be as high as 1,000 volts.

The larger cells require less labor per pound of aluminum produced, but special problems are encountered in cells designed to operate at 100,000 or more amperes. The larger currents cause powerful magnetic fields in the molten aluminum metal and the bath, resulting in violent agitation. This agitation causes aluminum to be dispersed in the bath, increasing the possibility of reversing the reduction reaction. Another detrimental effect is that the molten metal piles up toward the negative leads, causing a variation in the anode-cathode spacing.

Moreover, localized thermal effects may distort the carbon lining.

Production cells normally have current efficiencies ranging from 85% to 93%. Metal losses are principally caused by reoxidation of aluminum in the electrolyte and by physical loss of metal through vaporization from the bath or spillage. The resistance of the bath is sufficient to maintain the operating temperature. However, heat energy is lost by radiation, thermal conductance through electrode connections, in exhaust gases and tapped metal, and in electrodes removed from the cells.

To prevent atmospheric pollution, fumes evolved from the cells during electrolysis are removed from plant offgases by a collection and wet-scrubbing system or by a dry process whereby the fluorine is absorbed by alumina and recycled.

Superpurity Aluminum Processing.—The production of superpurity aluminum, 99.99+ % purity, requires special procedures, such as a continuous electrorefining of commercially pure aluminum in a Hoopes cell. This cell employs three molten layers of metals or bath materials of different densities. The bottom layer is the anode, a relatively impure aluminum alloyed with copper to increase its density. The intermediate layer is molten cryolite electrolyte with alkaline earth metal fluorides added to give the desired density, always greater than pure aluminum. The top layer, which serves as the cathode, is the molten superpurity aluminum that floats on the electrolyte layer.

Recycling.—In recycling, aluminum-base scrap is usually melted in gas- or oil-fired reverberatory furnaces of 30,000- to 100,000-pound capacity, sometimes with primary ingot metal. The furnaces have one or two charging wells separated from the main bath by a refractory wall that permits only molten metal into the main bath. The principal refining of aluminum-base scrap is the removal of magnesium by treating the molten metal with chlorine or with

various fluxes such as aluminum chloride, aluminum fluoride, or mixtures of sodium and potassium chlorides and fluorides. To facilitate handling, a significant proportion of the old aluminum scrap, and in some cases new scrap, is simply melted to form a solid ingot called "sweated pig," which must be further treated to produce specification-grade ingot.

Aluminum drosses containing about 30% metallics are usually crushed and screened to bring the metallic content up to about 60% to 70%. They are then melted in a reverberatory furnace, with the molten aluminum metal collecting on the bottom of the furnace. Salt slags containing less than 30% metallics may be leached with water to separate the metallics.

ANNUAL REVIEW— ALUMINUM

Domestic production of primary aluminum has been just over the 4-million-ton-per-year level since 1989. In 1991, domestic and world producers continued to operate their smelters at or near rated capacity levels during most of the year despite the economic recession, falling metal prices, and rising inventories. It was not until late in the year that producers began announcing temporary smelter closures and cutbacks in production. However, by then, prices were hovering around the 50-cent-per-pound range, their lowest level since late 1986.

The domestic secondary aluminum industry also fell victim to this economic squeeze of falling prices and rising inventories in 1991. Despite these problems, more than 2.5 million tons of metal was recovered from purchased new and old scrap during the year. Aluminum recovered from discarded aluminum products (old scrap) accounted for about 60% of this total. Almost 30% of the apparent demand for aluminum was met by metal recovered from old scrap.

The domestic consumption of aluminum decreased slightly in 1991. The overall weakness of the economy and

cutbacks in the construction and transportation industries contributed to this decline. Although U.S. imports decreased slightly in 1991, U.S. exports continued to grow, but at a much slower pace than at the end of the past decade.

The slowdown in worldwide aluminum demand, rising inventories, and declining metal prices led many companies to begin to reevaluate the status of their higher cost aluminum reduction facilities around the world. Many companies also began to reassess their primary aluminum expansion plans that were made during the high growth period of the late 1980's. The startup of this planned new capacity may well be delayed from the originally proposed timetables. (See table 4.)

Production

Primary.—Domestic primary aluminum production increased slightly compared with 1990 production levels. In 1991, 13 companies operated 23 primary aluminum smelters, and most of these smelters continued to be operated at or near their rated capacity levels during most of the year.

In February, Ravenswood Aluminum Co. reported the restart of one of two idled potlines at its primary aluminum plant in Ravenswood, WV. The restart brought production at the plant to about 75% of its 166,000-ton-per-year capacity. The potline had been closed since 1981.

In August, Reynolds Metals Co. announced the shutdown of three of the five potlines at its primary aluminum smelter in Troutdale, OR, curtailing about 70,500 tons per year of production capacity. In December, Reynolds Metals reported the temporary closure of the remaining two potlines at its 121,000-ton-per-year facility.

The Environmental Protection Agency (EPA) granted Reynolds Metals' petition to exclude kiln residue, derived from the processing of spent potliner, from EPA's list of hazardous wastes. Reynolds' process reportedly blended the potliner with limestone and a sandy material prior to roasting at elevated temperatures in a rotary kiln, converting the spent potliner into environmentally acceptable landfill

material. In 1988, the EPA had listed spent potliner as a hazardous waste. Reynolds' proposed plant in Arkadelphia, AR, the site of a dismantled primary aluminum smelter, reportedly would have the capacity to process 120,000 to 130,000 tons of spent potliner per year.

Alumax Inc. reported the closure of its aluminum rolled products plant in Hawesville, KY. The plant reportedly housed a single cold mill and produced aluminum sheet products for the building and construction industry.

Kaiser Aluminum & Chemical Corp. entered the automotive aluminum casting business with the announced purchase of the Winters Industries Div. of Whitaker Corp. Winters Industries produced manifolds and other cast aluminum components for cars and trucks and was one of four companies reportedly selected to supply aluminum engine components for the V-10 engine going into Chrysler Corp.'s Viper sports car. Winters Industries, which operated three plants in and around Canton, OH, would probably become part of Kaiser Aluminum's forgings division.

Reynolds Metals reported an increase in capacity at its Bellwood, VA, aluminum extrusion plant with the startup of a new, fully automated, 5,000-ton extrusion press. The new press resulted in a 25% increase in plant capacity to 100 million pounds per year.

Alcan Aluminum Corp. announced the opening of its new wire and cable facility in Roseburg, OR. The plant would produce aluminum transmission and distribution cable and aluminum building wire.

J W Aluminum Co. reported the completion of a 30-million-pound expansion at its Mount Holly, SC, fabrication facility. The plant produced foil, finstock, and coiled sheet for a number of applications, including cable wrap and litho sheet. (See table 5.)

Secondary.—According to a survey conducted by the Aluminum Association Inc., the Institute of Scrap Recycling Industries, and the Can Manufacturers Institute, a record 56.85 billion aluminum UBC's were recycled in the United States

in 1991, about 227 cans for every man, woman, and child in the Nation. This was the 20th consecutive year that the number of recycled aluminum beverage cans has increased. The recycling rate for 1991 was 62.4%, down slightly from the 1990 rate of 63.6%.

Golden Aluminum Corp. announced that construction had been completed at its new 130-million-pound-per-year canstock plant in San Antonio, TX. The company noted that the rolling mill would use continuous casting technology to manufacture aluminum sheet products for the food and beverage can market. The feedstock for this plant would be recycled material, primarily UBC's. The company expected the plant to come on-line by the end of the year and to begin full-scale operations early in 1992.

Roth Brothers Smelting Corp. announced plans to increase capacity at its East Syracuse, NY, secondary aluminum smelter by 25,000 tons per year. The company said the decision was based on projections for increased use of secondary aluminum in the automotive market.

Two companies announced plans to build plants to process saltcake, a byproduct of aluminum dross processing. Imco Recycling Inc. planned to build a salt recovery plant at its Morgantown, KY, plant, and Solar Aluminum Technology Services announced plans for a facility in Wendover, UT. Both plants were expected to recover both aluminum metal and reusable fluxing salts. (See tables 6, 7, and 8.)

Consumption and Uses

The container and packaging industry remained the largest domestic consumer of aluminum products and increased its share of the domestic aluminum market to 29%. The Can Manufacturers Institute reported that more than 91 billion aluminum beverage cans were shipped in 1991, representing about 97% of the total metal beverage can shipments.

Reynolds Metals announced the introduction of a new generation of canmakers, which it claimed operated at speeds one-third greater than the fastest

canmaker currently in wide commercial use. The new Mark IV draw-and-iron press reportedly could produce two-piece can bodies at the rate of more than 400 cans per minute. Prototype and production models were in operation in Greece and the United States.

Alcoa announced the development of a new high-strength aluminum alloy 7055-T77 for compression-dominated structures in the aircraft industry. The new alloy targets such applications as upper wing structures, cargo rails, and seat tracks. Boeing Co. announced that the new alloy had been specified for the upper wing skins on its new 777 wide-body aircraft.

Aluminum also found increased application as a major construction material in specialized marine crafts. A new rescue vessel designed for the U.S. Coast Guard contains about 7 tons of aluminum. The Coast Guard announced that Textron Marine Systems had been awarded a contract to construct five of these 47-foot crafts as an intermediate step to building up to 100 of the vessels. Textron reported that aluminum alloy sheet and extrusions used in the hull, keel, and engine foundations gave the vessel the strength to withstand wave impacts that were three times the acceleration of gravity. The craft was also designed to survive 360-degree side rollovers and end-over-end flips, to handle hurricane-force winds, to travel at speeds greater than 25 knots, and to have a range of 220 nautical miles.

Another marine application for aluminum was in high-speed catamaran passenger vessels, such as the new Seacat ferry that was put in service on the English Channel. For vessels such as catamarans, hydrofoils, and hovercraft/air cushion catamarans, light weight is particularly important, and aluminum has long been a favored construction material.

Aluminum continued to compete with other metals and plastics for an increased share of the automotive market. Reynolds Metals reported that it had been awarded a 5-year contract by the Ford Motor Co. for aluminum driveshaft tubes. The contract covered delivery of 500,000 tubes per year requiring an estimated

1,200 tons of aluminum annually. Both General Motors Corp. (GM) and Chrysler announced plans to begin switching from copper and brass radiators to aluminum radiators in various car and truck models over the next few years.

Ford reported that it had received commitments from Alcoa, Reynolds Metals, and Alcan Aluminium Ltd. to help in the development of body panel applications for aluminum in the next generation of the midsize Taurus cars scheduled to be introduced in 1995. These subassemblies—inner and outer hood panels, deck lid panels, and front fenders—would be evaluated against conventional steel units on the basis of weight, dent-resistance, appearance, corrosion-resistance, price, and other factors.

Chrysler announced plans to develop a two-stroke, low-profile, three-cylinder engine for passenger car use by 1995 that could contain as much as 100 pounds of aluminum versus the 50 to 55 pounds of aluminum contained in Chrysler's conventional four-cylinder, four-stroke engine. A similar type of engine reportedly was being developed by Orbital Engine Co. USA Inc. for use by Ford in Europe.

GM announced that it was developing a low-displacement engine for introduction in some of its intermediate and larger cars in 1994 that would employ an estimated 165 pounds of aluminum in the cylinder blocks, heads, water pumps, pistons, intake manifolds, and other components.

Creative Industries, Auburn Hills, MI, reported that it was teaming up with Alcan Aluminium to engineer a lightweight aluminum frame for GM's first production electric cars, which the company expected to be introduced in 1994.

Alcan Rolled Products announced plans to construct two pilot-processing lines for automotive sheet products at its Warren, OH, rolling mill. A company spokesman said that this marked a first stage in the product development phase and eventually would include joint testing and other procedures with the automobile companies.

Alcoa announced plans to build a plant to produce components and sub-assemblies for aluminum spaceframes in Soest, Federal Republic of Germany. The plant, scheduled for completion by 1993, was expected to have the capacity to produce more than 100,000 units annually. Alcoa also announced that an agreement had been signed with Audi AG under which Alcoa would supply aluminum spaceframe components for a new Audi model. (See tables 9, 10, 11, and 12.)

Stocks

Inventories of aluminum ingot, mill products, and scrap at reduction and other processing plants, as reported by the U.S. Department of Commerce, decreased from a revised total of 1.820 million tons at yearend 1990 to 1.788 million tons at yearend 1991.

On February 1, the LME began accepting metal at its first U.S. warehouse in Baltimore, MD. By the end of the year, the LME had approved warehouses for the receipt of aluminum metal in six additional locations in the United States—Long Beach, CA; Bridgeport-New Haven, CT; Chicago, IL; Louisville, KY; St. Louis, MO; and Toledo, OH. The LME reported that its U.S. warehouses held a total of 167,550 tons of aluminum metal at yearend 1991.

Markets and Prices

The monthly average U.S. market price of primary aluminum trended downward throughout the year. The December monthly average was more than 18 cents per pound lower than the January price level. The LME and New York Commodity Exchange (COMEX) prices for aluminum futures followed the same general trend as the U.S. market price.

Purchase prices for aluminum scrap, as quoted by the American Metal Market (AMM), fluctuated during the year, but closed the year at much lower levels than those at the beginning of the year. The yearend price ranges for selected types of aluminum scrap were as follows: mixed

low-copper-content aluminum clips, 38 to 39 cents per pound; old sheet and cast aluminum, 33 to 35 cents per pound; and clean dry aluminum turnings, 34 to 36 cents per pound.

Prices for UBC's fluctuated during the year, but closed 10 cents per pound lower than prices at the beginning of the year. Aluminum producers' buying prices for processed and delivered UBC's, which began the year in a range of 42 to 46 cents per pound, reached a high for the year of 49 to 53 cents per pound in March. The price range at the end of the year was 32 to 37 cents per pound.

Secondary aluminum ingot prices, as quoted by AMM, fluctuated during the year, but generally trended downward and closed much lower than prices at the end of 1990. The yearend 1991 price ranges for selected secondary aluminum ingots were as follows: alloy 380 (1% zinc content), 59.5 to 61 cents per pound; alloy 360 (0.6% copper content) and alloy 413 (0.6% copper content), 62.5 to 63.5 cents per pound; and alloy 319, 61 to 62.5 cents per pound.

The LME continued its investigations into the potential for an LME secondary aluminum ingot contract. A final decision on the introduction of such a contract was expected by mid-1992. (See table 13.)

Foreign Trade

Exports of all forms of aluminum from the United States increased slightly from those of the previous year. Canada and Japan continued to be the major recipients of U.S. aluminum materials, accounting for slightly more than 70% of the U.S. exports. Exports of UBC's, which were included in the scrap category, were at about the same level as those of the previous year. UBC exports in 1991 totaled 2,805 tons compared with 2,854 tons in 1990. Japan and the United Kingdom were the principal destinations of UBC's exported, accounting for almost 60% of the total in 1991.

Imports for consumption of aluminum decreased slightly compared with those of 1990. Canada remained the major shipping country to the United States,

supplying almost 84% of the total imports in 1991. UBC imports in 1991 totaled 31,602 tons compared with 37,028 tons in 1990. Canada also continued to be the major source of UBC imports, accounting for more than two-thirds of the total in 1991. (See tables 14, 15, 16, 17, and 18.)

World Review

With the slowdown in the world economy, which began during the latter half of 1990 and continued through 1991, world demand for primary aluminum remained relatively unchanged from that of the previous year. World inventories rose, especially those held by the LME. LME inventories at the beginning of the year totaled 318,000 tons. By the end of the year, inventories held by the LME had more than tripled and totaled 987,150 tons.

This oversupply of metal was exacerbated by a larger than normal influx of aluminum metal from the U.S.S.R. onto the world market. In previous years, Eastern European countries, including the U.S.S.R., shipped between 100,000 and 350,000 tons of metal per year to the Western World market. In 1991, however, it was estimated that these shipments exceeded 800,000 tons of metal.

Primary aluminum inventories held by members of the International Primary Aluminium Institute (IPAI), which represent the bulk of stocks held outside the former centrally planned economy countries, increased from 1.527 million tons at yearend 1990 to 1.754 million tons at yearend 1991. IPAI reported that total metal inventories, including secondary aluminum, increased from 3.138 million tons at yearend 1990 to 3.349 million tons at yearend 1991.

The slowdown in demand accompanied by rising inventories caused world aluminum prices to fall sharply. Even though it appeared that many of the world's smelters were operating at a loss, it was not until late in the year that companies began to announce temporary capacity shutdowns. The current oversupply of metal and the uncertainty

surrounding future exports from the U.S.S.R. has caused many companies to delay or postpone previously announced smelter expansion plans.

Capacity.—The data in table 19 are rated annual capacity for plants producing primary aluminum as of December 31 for the years shown. Rated capacity is defined as the maximum quantity that can be produced on a normally sustainable, long-term operating rate, based on the physical equipment of the plant and given acceptable routine operating procedures for labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. (See table 19.)

Argentina.—In October, Aluminios Argentinos S.A.I.C. (Aluar) announced plans to decrease production by 9% at its 160,000-ton-per-year primary aluminum smelter at Puerto Madryn. The cutback reportedly was in response to low world metal prices.

Australia.—Vereinigte Aluminium-Werke AG (VAW) reported that the Government of Australia had approved a proposed expansion of the consortium-owned Tomago Aluminium Co. Pty. Ltd. primary aluminum smelter in New South Wales. The addition of the proposed third potline would increase capacity at the smelter to 380,000 tons per year. The company reported that construction was scheduled to begin this year and that initial production from the new potline was expected in the first half of 1993.

The State government-owned Aluminium Smelters of Victoria Pty. Ltd. (Aluvic) and the wholly owned subsidiary of U.S.-based Adolph Coors, Golden Aluminum, announced the signing of a joint-venture agreement to build a 105,000-ton-per-year aluminum can sheet rolling mill at Bendigo. The new venture, Golden Pacific Aluminium, reportedly would use continuous casting technology developed by Launer

Engineering Ltd., the same technology developed for Golden Aluminum's rolling mill in San Antonio, TX. One major difference between the two plants, however, was that the San Antonio plant would use recycled metal as feedstock, while the Australian plant would use primary metal. Golden Pacific reported that it was proceeding with preliminary engineering plans and applications for environmental permits. If technical, financial, and permitting activities were resolved, construction could begin in the fourth quarter of 1992 with commissioning scheduled for late 1994.

Austria.—Reynolds Metals announced the completion of a \$16 million expansion that doubled the capacity of its Austria Dosen can plant at Enzesfeld, near Vienna. Capacity of the two-line plant increased to 900 million cans per year. Reynolds Metals said that the company was now positioned to grow in the future and to become a major supplier in the European market that consumed 58 beverage cans per capita compared with 350 cans per capita in the United States.

Austria Metall AG announced plans to close its 80,000-ton-per-year Ranshofen primary aluminum smelter by the end of 1992. The company planned to close the smelter in five stages, the first of which was scheduled for the end of 1991.

Bahrain.—Bahrain Aluminium Extrusion Co. (Balexco) announced the signing of a technical cooperation agreement with Finleader Group of Italy to expand Balexco's production from its current capacity of 6,000 tons per year to 18,000 tons per year. The company reported that work on the plans was scheduled to begin in 1992 and would include three units, an aluminum extrusion press, a casting remelt plant, and an aluminum die manufacturing plant.

Brazil.—Alumínio do Maranhão S.A. (Alumar) announced that the new third potline at its primary aluminum smelter in São Luis was fully operational. The addition of the 83,000-ton-per-year

potline increased the annual capacity of the smelter to 328,000 tons.

Alumínio Brasileiro S.A. (Albras) announced the completion of the Phase II expansion of its primary aluminum smelter, which increased capacity to 320,000 tons per year. In early March, a blackout that cut electrical power to the plant for 12 hours severely damaged the smelter. By the end of September, Albras reported that 814 of the plant's 864 pots were fully operational as opposed to 131 operating pots immediately following the blackout.

In November, Alcan Alumínio do Brazil S.A. announced the closure of one of three potlines at its 60,000-ton-per-year smelter in Saramenha. The closure reduced capacity at the plant by 9,000 tons per year.

Reynolds Metals announced plans to expand capacity at Latas de Alumínio S.A. (Latasa), a joint-venture can manufacturing plant. The \$30 million project reportedly would increase the plant's existing 800-million-can-per-year capacity to 1.3 billion cans per year.

Canada.—In February, Aluminerie de Bécancour Inc. (ABI) reported that the smelter's third 120,000-ton-per-year potline was fully operational, 4 months ahead of the planned completion date. Capacity at the plant rose to 360,000 tons per year.

Reynolds Metals announced the startup of a new 120,000-ton-per-year potline at its primary aluminum smelter in Baie Comeau, Quebec. With the addition of this potline, capacity at the plant increased to 400,000 tons per year, making this one of the largest smelters in the world.

Alcan Aluminium announced the temporary reduction of capacity at three of its smelters in Quebec. Effective November 1, one 21,000-ton-per-year potline at Shawinigan and one 24,500-ton-per-year potline at Isle Maligne were closed. In addition, one 22,000-ton-per-year potline at the Arvida smelter was closed at the beginning of December.

Kaiser Aluminum announced plans to build an extrusion plant in London, Ontario, at a cost of \$21 million. The

plant reportedly included three presses—4,000 tons, 2,400 tons, and 1,800 tons. The company expected the project to be completed in 1993 and to eventually replace the company's present extrusion plant in Scarborough.

Chile.—Noranda Aluminum Inc. announced that it reached an agreement with Proyectos de Aysen, a small Chilean company, to proceed with a proposed primary aluminum smelter in southern Chile. The \$1.5 billion Alumysa project reportedly included a 230,000-ton-per-year smelter, a hydroelectric plant, and a port facility near Puerto Aysen. Financing of the project was incomplete, and construction was expected to take about 6 years to complete.

China.—China reported that construction had begun on the first phase of the Pingguo Aluminium Co. in the Guangxi Zhuang Autonomous Region. The first stage, which the Government expected to be completed in 1994, called for a production facility with an annual capacity of 300,000 tons of alumina and 100,000 tons of aluminum. Upon completion of the project, Pingguo reportedly would have an annual production capacity of about 1.2 million tons of alumina, 500,000 tons of aluminum, and 300,000 tons of aluminum products.

Dubai.—In January, Dubai Aluminium Co. (Dubal) announced that its new 70,000-ton-per-year potline came on-stream 6 weeks ahead of schedule. Capacity at the smelter increased to 240,000 tons per year.

France.—Pechiney announced the permanent closure of two of its older primary aluminum smelters, Noguères and Riouperoux, at the end of October. The plant at Noguères, which had an original capacity of 114,000 tons per year before it was reduced to 75,000 tons per year in 1987, had reportedly been producing only 38,000 tons annually since October 1990. The Riouperoux smelter had an initial capacity of 25,000 tons per

year, which had fallen to 14,000 tons per year prior to the shutdown.

Germany.—Alusuisse Lonza Holdings Ltd. announced the closure of its 64,000-ton-per-year primary aluminum smelter in Rheinfelden. A combination of the age of the smelter, which was one of the oldest in Europe (startup 1897), the downturn in world aluminum markets, the high cost of energy, and increased environmental expenditures were cited as reasons for the closure. The company reported, however, that the casthouse at Rheinfelden would continue to produce primary aluminum casting alloys, impact extrusion semis, and items from the specialty foundry.

Alusuisse also announced a temporary 40,000-ton-per-year cutback in production at its 130,000-ton-per-year smelter in Essen.

At the end of October, VAW announced the temporary closure of 33,000 tons per year of capacity at two of its smelters in Germany. Most of the reduction was reported to be at its Töging smelter and the remainder at its Norf facility.

Subject to the approval of the German Federal Cartel Office, Klockner and Co. and SMG Sommer Metallwerke GmbH announced an agreement to merge their secondary aluminum activities and to form a new company, Sekundäraluminiumwerke GmbH (SAW). Sommer Metallwerke would own 80% of the new company, and the remainder would be owned by Klockner. Included in the merger were Sommer Metallwerke's three secondary aluminum plants, which produced about 130,000 tons per year of aluminum, and Klockner's 38,000-ton-per-year secondary aluminum plant.

Hungary.—Hungarian Aluminium Corp. (Hungalu) announced plans to close all three of its primary aluminum smelters in Hungary. The company indicated that the 18,000-ton-per-year Tatabánya smelter would close at the end of the year. The 25,000-ton-per-year Ajka smelter and the 35,000-ton-per-year

Inota smelter were scheduled for closure in 1992.

Iceland.—The Atlantal Aluminium consortium reported that attempts to secure financing for its greenfield smelter had been postponed. The partners cited low aluminum metal prices, weak demand, and uncertainty arising from developments in Eastern Europe as reasons for the decision, which could push back the originally proposed timetable for the project (1994) by as much as 3 years. The group said, however, that preliminary environmental and other preparatory work would continue.

India.—National Aluminium Co. Ltd. (Nalco) announced plans for a \$1.2 billion expansion program. According to company officials, the plan included a 50% expansion of capacity at its primary aluminum smelter in Orissa to 330,000 tons per year, a 25% increase in alumina refinery capacity, and a doubling of bauxite mine capacity.

Hindustan Aluminium Co. Ltd. (Hindalco) reported the commissioning of a sixth potline at its Renukoot smelter, raising capacity at the plant to 150,000 tons per year. The company also announced plans to double the capacity of this smelter and to expand the capacity of its captive powerplant by 360 megawatts.

Iran.—Almahadi Aluminium Corp. announced the signing of a construction contract for a new \$1.5 billion primary aluminum project at Bandar Abbas near the Straits of Hormuz. The 220,000-ton-per-year smelter was expected to come on-stream in mid-1994 and to be fully operational by mid-1995. The company also announced the possible future expansion of this smelter to 330,000 tons per year. Almahadi Aluminium was a joint venture between the Iranian Government (60%) and the Dubai-based International Development Corp. (40%).

The Government also reported that work was proceeding on the addition of a new fourth potline at the primary smelter in Arak. The new potline was due on-

stream in October. Installation of a fifth potline reportedly was underway and due to come on-stream in 1992. Completion of the fifth potline was expected to increase capacity at the smelter to 120,000 tons per year.

Italy.—Alumix S.p.A. announced the closure of its 30,000-ton-per-year primary aluminum smelter at Porto Marghera. The closure was the first step in a major reorganization plan announced by the State-owned aluminum producer.

Japan.—Kobe Steel Ltd. and Alcoa announced the formation of two more joint-venture companies, one in the United States and the other in Japan. The companies were expected to focus on expanding the use of aluminum in the automotive industry and to include joint research and development in aluminum sheets, extrusions, castings, and forgings, as well as production and sales.

Nippon Steel Corp. reported an agreement to purchase 26.25% of Sky Aluminium Co. from Mitsui and Co. Ltd., increasing Nippon's share of the company to 36.25%. Sky Aluminium reportedly produced approximately 117,000 tons per year of aluminum sheet.

Yet another joint venture between a steel company and an aluminum producer was announced. Kawasaki Steel, Furukawa Electric, and Furukawa Aluminium announced plans to set up aluminum sheet production facilities to serve the automobile industry.

Sumitomo Corp. announced the merging of two of its subsidiaries, Kansai Light Metals and Sumi-Al Alloys. The new company, Summit Aluminium, was expected to have an aluminum alloy capacity of 120,000 tons per year. Because Sumi-Al produced alloy from primary ingot and Kansai produced alloy from scrap, the new company was expected to vary its raw material intake based on price fluctuations between primary and secondary materials. Summit also announced a 5-year expansion plan that was expected to increase alloy capacity by 5,000 tons per month.

Korea, Republic of.—Adolph Coors Co. announced the signing of a joint-venture agreement with Jinro Ltd., a large food and beverage company in Seoul. The joint venture, Jinro-Coors Brewery Co., reportedly included a 1.8-million-barrel-per-year brewery and an on-site aluminum can plant.

Alcoa and Sam Sun Industrial announced the formation of a joint venture to produce aluminum extrusions and tube products principally for the South Korean aerospace market.

Mexico.—Aluminio SA announced the closure of two of the three potlines at its 66,000-ton-per-year primary aluminum smelter in Vera Cruz. By the end of the year, operating capacity at the smelter had been reduced to 22,000 tons per year.

Netherlands.—Late in the year, Hoogovens Aluminium BV announced an 18,000-ton-per-year decrease in primary aluminum smelter capacity. Hoogovens operated smelters at Delfzijl in the Netherlands and Voerde in Germany.

Pechiney Nederland NV announced a 12.5% decrease in production capacity at its 170,000-ton-per-year smelter in Vlissingen.

Norway.—Norsk Hydro AS joined the list of companies that announced temporary cutbacks in production owing to rising world inventories and declining metal prices. In November, Norsk Hydro announced temporary cutbacks of 45,000 tons per year, equivalent to 7.5% of capacity, to take effect by the end of the year. All four of the company's Norwegian smelters would be included in the reductions.

Alcoa announced the purchase of Elkem AS's 50% interest in Alcoa Nederland Holdings BV. By purchasing Elkem's share, Alcoa became the sole owner of the rolled and extruded aluminum products company. The purchase included fabrication facilities in the Netherlands, Spain, and the United Kingdom, but did not affect the Elkem-

Alcoa partnership that operated primary aluminum smelters at Lista and Mosjoen.

South Africa, Republic of.—Alusaf Pty. Ltd. announced plans to build a new 466,000-ton-per-year primary aluminum smelter in the Republic of South Africa. The company also reported that a technology agreement had been signed with Pechiney, whereby the French company would design the facility and provide 2 years of operational support. A final decision on the project was expected in 1992. If the go-ahead is given, the company said that full commercial production could be achieved within 3 years.

Spain.—Pechiney announced plans to construct an aluminum beverage can plant near Barcelona. The company expected the facility to be completed in the first quarter of 1992 and to produce 1.2 billion cans per year.

Turkey.—Etibank announced plans to expand capacity at its 60,000-ton-per-year smelter in Seydisehir to 100,000 tons per year.

United Kingdom.—Alcan Aluminium announced a temporary reduction in production at two of its primary aluminum smelters. In July, 10,000 tons per year of production was curtailed at Lochaber. In November, Alcan Aluminium closed one 66,000-ton-per-year potline at Lynemouth Works.

Alcan Aluminium also announced the opening of a UBC recycling plant in Warrington. The 50,000-ton-per-year plant reportedly was the first recycling plant in the European Community dedicated solely to the recycling of aluminum beverage cans.

Cookson Aluminium announced that construction had begun on a new secondary aluminum smelter at Repton near Derby. Although the new smelter would have a design capacity of 30,000 tons per year, the net increase in capacity for Cookson would be only 5,000 tons per year. The new smelter was to replace the recently mothballed 10,000-

ton-per-year smelter at North Cave on Humberside and the existing 15,000-ton-per-year smelter at Repton. The company expected the new smelter to be completed in 1992.

Nacanco reported the completion of a third production line at its Wakefield aluminum beverage can plant. The new line reportedly increased the annual capacity of the plant by 50%, from 1.2 billion cans to 1.8 billion.

CMB Packaging announced that it had converted one of the five canmaking lines at its Carlisle plant from the production of tinsplate soft drink cans to aluminum beer cans. The modified line reportedly had a production rate of 800,000 cans per day. A spokesperson for the company said that, because of a growing preference for aluminum, the plants' three remaining steel lines could be switched to aluminum in the future.

Venezuela.—The Government of Venezuela announced the selection of three new aluminum smelter projects to participate in its debt-for-equity financing program. The projects selected were: Alcoven, a 300,000-ton-per-year Alcoa-based project; a 240,000-ton-per-year Orinoco project, which included Kaiser Aluminum and Korean interests; and Aluyana, a 215,000-ton-per-year smelter, which included Italian interests. Also qualified under this debt-equity program was the Quintametall Project (Alcasa V), the addition of a fifth potline, equivalent to 215,000 tons per year of capacity, at the Aluminio del Caroni SA (Alcasa) smelter in Puerto Ordaz. (See table 20.)

Current Research

Intermetallic compounds containing aluminum, such as nickel aluminide (NiAl), offered new opportunities for developing low-density, high-strength structural alloys, which might be used at temperatures higher than currently possible with conventional titanium- and nickel-base alloys. An article describing the physical and mechanical properties of NiAl, its application potential, and the progress made in improving its mechanical properties was published.⁴

Under a program funded by the U.S. Air Force, the manufacture of discontinuously reinforced aluminum composites was being scaled up to commercially useful sizes and production rates. An integral part of the attempt to scale up the production of these composites was the evaluation of the properties of the materials produced so that specifications could be maintained. Among the composites being tested were 6090/SiC/25p, which was designed for ambient-temperature applications, and X8019/SiC/12.5p, which was designed for elevated-temperature applications.⁵

The performance requirements of advanced naval aircraft, weapons, and propulsion systems have necessitated the development of a new category of hybrid materials: HYMATS. The Naval Air Development Center was actively engaged in research and development on several HYMAT materials, including macrolaminates; polymets; conductive, segregated-network composites; and reinforced ceramics.⁶

The Minerals, Metals, and Materials Society (TMS) published the proceedings of the Light Metals Committee technical sessions presented at the 120th TMS Annual Meeting held in New Orleans, LA, February 1991. More than 100 papers, in such topic areas as alumina and bauxite, reduction technology, carbon technology, and cast shop technology, were presented. The proceedings, entitled, "Light Metals 1991," were available from TMS, 420 Commonwealth Drive, Warrendale, PA 15086.

OUTLOOK—ALUMINUM

Demand for aluminum, both domestically and worldwide, continued to be weak during the first half of 1992. The oversupply of metal, the economic recession, and the uncertainty surrounding future metal export levels from the former U.S.S.R. should continue to depress the world aluminum market. This slowdown should continue into 1993 before beginning a slow gradual rise in the second half of the year. Once the market adjusts itself to the flow of metal from the former

U.S.S.R. into the world marketplace and the world economies begin to recover, the aluminum market should also begin to recover. Thereafter, aluminum metal demand should show an average annual growth rate of about 2% per year over the next few years.

ANNUAL REVIEW—BAUXITE AND ALUMINA

World production of bauxite and alumina declined throughout 1991 in a marked response to the worldwide slowdown in demand for primary aluminum metal. Mine production of bauxite was reported from 27 countries. Domestic consumption of bauxite, contrary to world production trends, once again continued its upward movement during the year, with the majority of this growth driven by requirements resulting from the sustained high operating rates of U.S. aluminum smelters and alumina tolling operations. Within the specialty products area, consumption of chemical-grade bauxite increased by a small amount above 1990 levels, but bauxite consumption by the abrasive and refractory industries declined slightly in 1991. In spite of a protracted national economic recession in 1991, domestic demand for alumina remained firm through most of the year, chiefly in response to the continued high level of primary aluminum smelter operation. Total U.S. alumina production remained relatively constant in comparison with that of 1990, while shipments of smelter-grade alumina continued the upward progression that has been their pattern for the past 2 years. U.S. consumption of bauxite for alumina production increased slightly above 1990 levels; however, a significant softening of the alumina market developed for alumina priced on contracts tied to the depressed primary aluminum metal prices. This resulted in a pronounced weakening of the spot prices quoted for alumina on world markets in 1991. Alumina reportedly was produced in 24 countries around the world. (See table 21.)

Legislation and Government Programs

On June 13th, 1991, the EPA issued a final determination that 20 special wastes from ore and mineral processing operations should not be regulated as hazardous materials.⁷ This finding included red and brown muds generated from Bayer-process production of alumina. All of the wastes had been identified for temporary exemption from regulation as hazardous materials under the Mining Waste Exclusion of the Resource Conservation and Recovery Act (RCRA) pending an EPA study and ruling. The EPA decision allows these wastes to be included within a special regulatory category being developed for mining extraction and beneficiation wastes.

There were no announced additions or withdrawals of bauxite from the National Defense Stockpile (NDS) in 1991. The NDS goals for bauxite remained unchanged at 21.3 million tons of Jamaica-type and 6.2 million tons of Suriname-type metallurgical-grade bauxite. The goal for calcined refractory-grade bauxite remained at 1.26 million tons. The Defense Logistics Agency (DLA), manager of the NDS, listed an inventory of 12.7 million tons of Jamaica-type and 5.4 million tons of Suriname-type metallurgical-grade bauxite at yearend. The NDS calcined refractory-grade bauxite inventory was listed as 280,500 tons at the close of 1991.

The Defense Logistics Agency (DLA) issued a solicitation on June 3, 1992, for the conversion of approximately 166,400 tons of NDS bauxite into aluminum metal. In this offering, the second of a planned series of contracts to upgrade NDS metallurgical-grade bauxite ore, compensation for fulfillment of the contract was stipulated to be by payment-in-kind with 1.6 million tons of NDS bauxite. The final award of a contract for this DLA solicitation was not announced by the end of the year.

Production

The total U.S. bauxite production during 1991 was markedly lower than that reported for 1990. The significant reduction in domestic mine production was partly attributed to the permanent closure of the last bauxite mining operation in Arkansas during mid-1990. The only currently active bauxite mines remaining in the United States are the surface operations in Alabama and Georgia that produce bauxitic materials, a natural mixture of bauxitic clay and bauxite with a very low iron oxide content, primarily used for the production of alumina calcines. Demand for these domestic ores remained relatively weak during 1991, and mine output was intermittent. The current proprietary nature of U.S. bauxite production data precludes the disclosure of this information in a nonaggregate form. Within this market sector, the Harbison-Walker Refractories Div. of Dresser Industries Inc. shipped bauxite from mines in Alabama to its local calcining plant and to Carbo Ceramic Co.'s proppant plant at Eufaula, AL. Throughout the year, C-E Minerals continued to operate and maintain its mines in Alabama and Georgia, with the raw ore shipped to its Andersonville, GA, facility for the production of high-alumina refractory materials. American Cyanamid Co. continued to produce calcined bauxitic clays for the production of aluminum sulfate at its Andersonville, GA, operation. In early 1991, Alcoa announced a major cost-cutting plan for its alumina chemicals plant at Benton, AR, a program that could result in a staff reduction of up to 40%. The labor force cuts were scheduled to begin by midyear, with completion of the total restructuring plan projected to take approximately 1 year. Additionally, later in the year, Alcoa announced plans to expand its facilities for drying alumina trihydrate at its Point Comfort, TX, alumina plant.

In December 1991, LaRoche Chemicals Inc. announced that it planned to construct a new activated alumina plant and expand two existing activated alumina

plants at its Baton Rouge, LA, facility. The total cost of the project was estimated at \$19 million, with startup for the new state-of-the-art plant scheduled for June 1993. Upon completion of the project, LaRoche's total production capacity for activated alumina should reach 27,000 tons per year.

During the second half of 1991, in order to balance its alumina supply system, Reynolds Metals temporarily reduced production at its Sherwin alumina plant near Corpus Christi, TX. On December 31, 1991, the Sherwin plant was reported to be operating at 69% of its annual rated capacity.

The merger of Vista Chemical Co. of the United States into RWE A.G. of Germany reportedly was completed in June 1991. The merger, originally announced in December 1990, was delayed by the Federal Trade Commission (FTC) until arrangements were developed to separate Vista Chemical's ultrahigh-purity alumina production, a byproduct of its Ziegler synthetic linear alcohol production process, from the remainder of Vista Chemical. The FTC-mandated solution to the separation issue was achieved when Discovery Chemicals Inc., of Port Allen, LA, and RWE formed a separate joint-venture company to market the monohydrate alumina byproduct obtained from Ziegler-process production of linear alcohols. This unique ultrahigh-purity alumina is one of the raw materials used in the manufacture of catalysts. (See tables 22 and 23.)

Consumption and Uses

A continued, firm domestic requirement for smelter-grade alumina moved the consumption of crude and dried metallurgical-grade bauxite to a level moderately above that of 1990. Consumption of bauxite by the chemicals industries increased very slightly during 1991, while consumption within the abrasive and refractory industries decreased by modest amounts for the year. Approximately 90% of the bauxite consumed in the United States during 1991 was refined to alumina, and an

estimated average of 2.17 tons of dried bauxite was required to produce 1 ton of calcined alumina. Twenty-two of the 23 active primary aluminum smelters reported a consumption of 8.1 million tons of calcined alumina in 1991, a slight increase from the consumption level reported for 1990. This greater level of consumption, coupled with the sustained high U.S. alumina production rates, resulted in an increased level of smelter-grade alumina imports into the domestic alumina market. An estimated 92% of the alumina shipped by U.S. refineries went to domestic primary smelters for metal production. Consumption in various forms by the abrasives, chemicals, refractories, and specialties industries accounted for the balance of the alumina usage. (See tables 24, 25, 26, 27, and 28.)

Markets and Prices

Contract terms for the purchase of metallurgical-grade bauxite and smelter-grade alumina in world markets are not normally made public, and, consequently, prices for these commodities are not published by trade journals. Price quotes are generally limited to certain specialty forms of bauxite and alumina for nonmetallurgical uses.

In 1991, the U.S. Bureau of Mines estimated the average value of domestic crude bauxite shipments, f.o.b. mine or plant, to be \$17 per ton. The average value of calcined domestic bauxite was estimated to be \$100 per ton. Base prices quoted by Industrial Minerals magazine and independent sources for imported calcined refractory-grade bauxite were as follows: Chinese, typical 85% alumina (Al_2O_3), f.o.b. barge, Burnside, LA, \$85 to \$125 per ton; and Guyanese, f.o.b. rail car, Baltimore, MD, or f.o.b. barge, Gulf Coast, \$175 per ton. Abrasive-grade bauxite, minimum 86% Al_2O_3 , c.i.f. main European ports, was priced at \$95 to \$108 per ton. Base prices were subject to adjustment for various grain-size specifications, size of order, and fuel cost factors.

The extremely low aluminum metal prices of 1991 resulted in a correspondent

easing of alumina prices from the record-high levels that were established during the late 1980's. The average value of domestic calcined alumina shipments was estimated to be \$230 per ton. Trade data released by the Bureau of the Census indicated the average value of imported calcined alumina was \$234 per ton, f.a.s. port of shipment, and \$248 per ton, c.i.f. U.S. ports. Beyond these current prices, medium-term projections support a reasonably buoyant market outlook for alumina toward the mid-1990's.

For 1991, the International Bauxite Association (IBA) recommended that its members set their minimum c.i.f. price for metallurgical-grade bauxite at between 2% and 2.5% of the composite reference price for primary aluminum ingot, and for metallurgical-grade alumina between 13.5% and 15.5% of the composite reference price for primary aluminum ingot. The IBA members account for approximately 85% of the bauxite output from the market economy countries and about 57% of the alumina production. (See tables 29 and 30.)

Foreign Trade

Dried bauxite exports from the United States totaled 37,800 tons in 1991, a continuation of the upward trend recorded in 1990; Canada received 32,100 tons and Mexico 5,000 tons. U.S. exports of calcined refractory-grade bauxite totaled 6,900 tons for 1991; Mexico received 5,800 tons and Canada 1,000 tons. Exports of all other grades of calcined bauxite (chiefly abrasive-grade) amounted to 6,000 tons for the year. Mexico received 5,600 tons of this total. Specialty aluminum compounds exported included 4,400 tons of aluminum sulfate, 10,800 tons of aluminum oxide abrasives, and 24,000 tons of various fluorine-base compounds of aluminum, including synthetic cryolite and aluminum fluoride.

Imports for consumption of crude and dried bauxite decreased from 1990 receipts, and the three primary suppliers were Jamaica, Guinea, and Brazil, in order of shipments. Australia's shipments to the United States decreased by approximately 70% during the year,

and Australia took up the fifth place position on the list of countries that supplied bauxite to U.S. markets in 1991. (See tables 31, 32, 33, and 34.)

World Review

World production of bauxite and alumina declined in response to a marked sluggishness in demand for primary aluminum metal. Twenty-seven countries reportedly mined bauxite in 1991, and the total world production of bauxite was slightly more than 109 million tons, a very slight decrease (less than 1%) below 1990 production. Australia, Guinea, Jamaica, and Brazil, in order of volume, accounted for slightly more than 70% of the total bauxite mined during the year. The corresponding world output of alumina decreased to 39.8 million tons, which was almost 1% below the 1990 production level. The traditional principal producing countries, Australia, the U.S.S.R., and the United States, once again supplied 50% of the total world production. Jamaica's reopened alumina capacity and plant expansions have allowed that nation to once again hold a principal position within the ranks of the world's premier alumina producers.

Capacity.—The 1991 world annual rated capacity of plants producing alumina was placed at 1% above last year's record-setting level. Apparent worldwide refinery capacity utilization for the year was estimated at approximately 90%. Any further free market increases in smelter-grade alumina production capacity are expected to develop from incremental expansions of existing plants and only in very special circumstances from new greenfield refineries, which normally require a 4- to 5-year design, engineering, and construction period, plus a rather substantial capital investment.

Australia.—In 1991, the world's largest bauxite- and alumina-producing country achieved a new alumina production record for the ninth consecutive year. Australian bauxite production in 1991, however, was below

the level recorded for 1990. This was the first drop in bauxite production levels for Australia since 1982.

In the latter part of 1991, it was reported that the Gladstone alumina plant in Queensland, operated by Queensland Alumina Ltd. (QAL), had reached a production level near 3.3 million tons per year. The successful introduction of a trihydrate-grade "sweetener" from the Weipa bauxite mining operations of Comalco Ltd. into the QAL Bayer circuit and the conversion from fuel oil to natural gas for calcination had contributed to this improvement in production.

During 1991, the Mineral Products Div. of Comalco reported that, in an effort to maintain its market competitiveness, it had instituted a series of work force reductions. The cutbacks included staff at the Weipa bauxite mining operations and the group's headquarters in Brisbane.

Australia announced that it intended to resign as a member of the Jamaica-based International Bauxite Association (IBA), which it had helped to create in 1974. Australia's Minister of Resources reportedly indicated the country had found that participation in the IBA was no longer justifiable on a cost versus benefits basis. Australia reportedly had tentatively set the date for withdrawal from the association as October of 1992.

Brazil.—Billiton International Metals BV and Alcoa reportedly decided not to proceed with their planned joint-venture development of a 2.25-million-ton-per-year bauxite mine near Oriximiná in the Brazilian State of Pará. Alternatively, Alcoa intends to become a shareholder in Mineração Rio do Norte's (MRN) Trombetas bauxite mining operation. In a related action, Alcan will exchange 12% of its participation in MRN for a 10% interest in the Alcoa-Billiton 1-million-ton-per-year São Luís alumina plant in Maranhão State.

In a related issue, the Brazilian Government granted Alumar approval to invest \$450 million for the expansion of its alumina plant at São Luis to the 2.1-million-ton-per-year level, with

completion of the project expected by 1994.

Cia. Brasileira de Alumínio (CBA) reportedly has decided to invest \$200 million to build a 200,000-ton-per-year alumina plant in east-central Minas Gerais State. The project had been on hold since 1989 because CBA was required to obtain both State and Federal authorization for the proposed development plan.

Canada.—During 1991, Alcan Aluminium commissioned a superwhite hydrate facility at its alumina plant at Jonquiére, Quebec. The new installation will produce commercial alumina-based chemicals for markets within North America.

In addition, Alcan announced that it had placed its Bayer Experimental Centre in Quebec into operation. The pilot plant provides a facility for carrying out experiments associated with the processing of bauxite and alumina. The research installation was designed to enable Alcan and its partner, Comalco, to develop the design of a new joint-venture alumina plant being considered for the Weipa area of Australia.

China.—As previously indicated, according to Chinese officials, the first phase of construction at the Pingguo Aluminium facilities in Guangxi Zhuang Autonomous Region was reported to have begun in 1991. Under this initial phase of the project, scheduled for completion in 1994, a 300,000-ton-per-year alumina plant and a 100,000-ton-per-year aluminum smelter are reportedly being constructed at a cost of \$519 million. It was planned that the bauxite feed for this aluminum complex would be drawn from five nearby mining areas where ore reserves have been estimated at 200 million tons.

Greece.—The Greek Government was reportedly seeking private investors to participate in the Hellenic Alumina Industry SA (ELVA) alumina plant planned for construction at Thisvi, in Boeotia. In the past 2 years, the cost of

this project has escalated from \$650 million to approximately \$850 million, owing in part to design modifications that have increased the plant's originally planned capacity from 600,000 tons per year to the currently contemplated 700,000 tons per year.

Guinea.—Mine planning and development for the Bidikoum bauxite deposit commenced in late 1991. The blending of ores from this newly opened mine site in the Boké region, with those from the adjacent Sangaredi Mine, will extend the overall life of the 12-million-ton-per-year Compagnie des Bauxites de Guinée (CBG) mining operation.

Guyana.—Aroaima Mining Co., a 50-50 joint venture of Reynolds Metals and the Government of Guyana, attained its full annualized mine production capacity of 1.5 million tons in 1991. The consortium, based in Barbados, has developed two mining sites along Guyana's Berbice River, with combined bauxite reserves of 25 million tons. The project's initial bauxite output was mined for sale to third-party buyers, as well as for purchase by Reynolds.

The Bauxite Industry Development Co. Ltd. (Bidco) and its subsidiary Guyana Mining Enterprise, Ltd. (Guymine) announced that they were considering the appointment of an engineering or mining company to undertake the management and restructuring of their principal bauxite production facilities at Linden. The Guymine Linden operations reportedly has a capacity of approximately 400,000 tons per year of mostly refractory-grade bauxite.

Hungary.—On June 30, 1991, Hungalu, a state-owned enterprise, was transformed into a public limited company according to the provisions of Hungarian Act XIII of 1989 dealing with the reorganization of economic organizations within Hungary.

As earlier noted, in the painful process of transition to a free market industry, Hungalu at midyear announced that it

planned to phase out its primary aluminum production, but would maintain operations at its three alumina plants and its semifabricating facilities. Hungalu intended to maintain these operations as profit centers for the attraction of investors into various privatization ventures.

Hungalu's bauxite production base shrunk in 1991 when two of five mines, both underground operations, were closed to ease the strain of mine dewatering procedures on the level of the regional water table.

India.—It was announced that India's state-owned Nalco received formal Government approval to expand existing operations at its Orissa complex by 50%. Nalco indicated that work on the expansion was scheduled to commence in 1992, with final completion of the project in 1995. The program reportedly includes a doubling of bauxite output from 2.4 to 4.8 million tons per year at its Panchapatmali mines in Koraput District, plus an increase of alumina production from 0.8 to 1.35 million tons per year at its Damanjodi plant, Koraput District.

The Government of India reportedly has decided, under its new liberal economic policies, to open bauxite mining to the private sector. This has led to the States of Gujarat and Andhra Pradesh providing invitations to private firms for the development of their respective bauxite deposits. The Gujarat Mineral Development Corp. released plans for the establishment of a 50,000-ton-per-year bauxite calcination plant.

Indonesia.—It was announced that Indonesia's state-owned PT Aneka Tambang intended to expand bauxite production by developing a deposit at Lomesa on Bintan Island, contingent upon approval from the local authorities. Under a 30-year contract, the company holds the exclusive mining rights for a 10,470-hectare mining concession on Bintan Island. Ore reserves for the Lomesa area reportedly have been estimated at 4 million tons of bauxite.

The PT Indonesia Asahan Aluminum (Inalum) smelter reportedly canceled contracts for 48,000 tons of alumina due to a 25,000-ton-per-year cutback in aluminum metal production. Inalum was forced to reduce its power usage, and as a result its metal output, because light rainfall had limited hydroelectric production at its affiliated power facilities on the Asahan River.

Iran.—The Iranian Ministry of Mining and Metal Industries reportedly awarded a \$357.2 million contract for the construction of a 250,000-ton-per-year alumina plant in Iran to the Hungarian aluminum industry's Planning and Research Institute (ALUTERV).

Italy.—In June 1991, Sardabauxiti S.p.A., a subsidiary of the Sardinian state-backed Ente Minerario Sardo, officially inaugurated its 350,000-ton-per-year Olmedo underground bauxite mine in the Nurra region of northwestern Sardinia. In addition to Olmedo, Sardabauxiti reportedly was developing plans to mine the near-surface bauxite deposits at Montigiù de Su Cossu.

Jamaica.—The Alumina Partners of Jamaica (Alpart) alumina plant, owned by Kaiser Aluminum (65%) and Hydro Aluminium (35%), reportedly produced 1.3 million tons of alumina in 1991. This was an increase of 110,000 tons compared with that of 1990. In conjunction with this production increase, the first phase of a modernization and expansion program to increase Alpart's capacity to 1.45 million tons per year was being implemented during 1991, with completion of the capacity increase expected for yearend 1992. A further expansion of annual capacity to 2 million tons per year was reportedly being considered by the participants in Alpart.

It was announced that Alcan would spend \$200 million to upgrade and expand its bauxite mining and alumina production facilities in Jamaica. The expansion program included the construction of a 2.5-mile cableway for

the transportation of bauxite from mines in the Comfort area to the Alcan Jamaica Ltd. alumina plant at Kirkvine, Manchester.

In 1991, it was reported that Jamaica's Government-owned Bauxite and Alumina Trading Co. (Batco) had signed a new 3-year agreement with Pechiney for the supply of 150,000 tons per year of bauxite.

Political changes within the U.S.S.R. late in 1991 reportedly resulted in the premature termination of a \$125 million, 5-year agreement for Jamaica to provide 1 million tons per year of bauxite to the U.S.S.R.

Netherlands.—It was announced that the Dutch aluminum smelter, Aluminium Delfzijl BV, a unit of Hoogovens, entered a new 7-year alumina supply contract with Royal Dutch/Shell's metals subsidiary, Billiton Marketing & Trading BV.

Sierra Leone.—It was announced that Alusuisse Lonza continued its negotiations in 1991 with the Sierra Leone Government regarding the updating and modification of existing bauxite mining contracts. The talks that commenced in 1990 apparently were open-ended and the existing mining agreement remains in effect until the parties reach a new agreement.

Suriname.—Suriname Aluminium Co. (Suralco) announced that its Coermotibo bauxite mine in Suriname was scheduled to come on-stream in mid-September. When fully operational, this mine should replace the Moengo mining operations, where reserves reportedly are nearly exhausted.

Additionally, in further mining developments, a new 500-ton bucket wheel excavator with its support equipment was delivered to Suriname in early 1991 to be used by Billiton Maatschappij Suriname (BMS) for overburden removal at the new Accaribo Mine near Paranam, a joint-venture operation between BMS (76%) and Suralco (24%).

U.S.S.R.—The Government of the U.S.S.R. reportedly ceased financing capital improvements at the Severoural'sk bauxite mine in Sverdlovsk Oblast. The underground mining operations reportedly exploit bauxite ores from depths of over 1,000 meters with substandard equipment and under very dangerous operating conditions. This disruption in funding may require the mothballing of the 12 projects that were under construction by the Boksitstroy Trust to make up for recently declining production levels. The new equipment and facilities, worth an estimated \$22 million, were due to come on-stream in 1992.

Venezuela.—It was reported that C.V.G.-Interamericana de Alumina, C.A. (Interalumina) of Venezuela had completed a \$350 million expansion program that increased its alumina production capacity from 1.3 to 2 million tons per year. In addition, Venezuela's C.V.G. Bauxita Venezolana C.A. (Bauxiven) announced that its 1991 ore production reached approximately 2.0 million tons, an exceedingly significant increase over 1990's 771,000 tons. During 1991, Bauxiven reportedly invested \$85 million to increase efficiency at its Los Pijiguaos mining operations, and it estimated a similar investment for 1992. (See tables 35, 36, and 37.)

Current Research

In 1991, Alcan International Ltd. announced the results of research into pilot plant tests for the conversion of Bayer-process-produced sodium oxalate to oxalic acid by an ion-exchange process.⁸ During Bayer processing of bauxite ores, organic carbon contaminants within the ores undergo degradation to sodium oxalate that builds up to equilibrium concentrations and remains in the recycled Bayer liquor of an alumina plant. This sodium oxalate causes processing and product quality problems in the production of alumina and, therefore, must be removed from the liquor when its concentration approaches the supersaturation point. Oxalic acid is

a commodity with extensive industrial applications; i.e., as a laundry bleach, a cleansing agent for metals, a textile finishing agent, and in the manufacture of dyes. The concept of converting sodium oxalate derived from the Bayer process to oxalic acid is not a new industrial strategy; VAW was granted a patent in 1977 for a similar byproduct approach based on the reaction of oxalate with lime at elevated temperature. Alcan's tests were conducted on a pilot plant scale for the preparation of a concentrated solution of oxalic acid as well as the recovery of acid dihydrate by the ion-exchange process, a less complicated and possibly safer method than that tested by VAW. The Alcan research work determined that the ion-exchange technique was a technically viable process for the transformation of Bayer sodium oxalate into oxalic acid. The method was simple to operate and required little maintenance and was found capable of generating some degree of cash-flow.

In related research, associated with seeking improvements to the Bayer process, Aluminium Oxid Stade GmbH (AOS), a 50-50 joint venture of VAW and Reynolds Metals, reported on its methods for the removal of organic carbon from Bayer liquor by wet oxidation in tube digesters.⁹ This research work, on an industrial scale, at AOS's Stade, Germany, facility, determined that maintaining less than 1% oxygen in the waste gases of the tube-digester units resulted in safe wet oxidation during oxygen injection into superhigh temperature tube digestion systems. The primary reason for this application of wet oxidation methods at AOS has been to slowly reduce, over a long period; i.e., years, the organic carbon content of the plant's Bayer circuit liquors.

OUTLOOK—BAUXITE AND ALUMINA

Known world bauxite reserves are sufficient to meet cumulative world demand well into the 21st century. Considering the high degree of

probability for discovering additional bauxite deposits and assuming reasonable energy costs, plus the added possibility of utilizing lower grade bauxite deposits and other alternative sources of alumina, world resources of aluminum are more than adequate to fulfill demand for the foreseeable future.

The shift of alumina production facilities from the aluminum-producing industrial countries with high energy costs, in North America and Europe, to the bauxite-producing countries of the world is expected to continue in the future. If the costs of imported bauxite and alumina increase for U.S. companies, alternate domestic sources of alumina may become economically more attractive feedstocks for the aluminum industry. Alternatively, high fuel prices tend to make nonbauxitic materials less competitive because the processes for treating substitute materials require considerably greater amounts of energy than that for Bayer-processed bauxite. It therefore seems evident that nonbauxitic sources of aluminum would become viable only within the context of a prolonged national emergency or international embargo extending over a period of several years. Imports of primary aluminum metal from countries with low electrical energy costs and secondary production from recycled aluminum appear likely to be used in ever-increasing proportions to meet the domestic demand for aluminum.

In addition, the future economic restructuring of Eastern Europe and the U.S.S.R. may greatly expand the potential market opportunities available to the firmly established bauxite- and alumina-producing countries of the world. The quality and quantity of bauxite resources within the former Eastern bloc nations are estimated to be incapable of sustaining an economically sound market-based aluminum industry. To become competitive in the "new global economy," major amounts of imported bauxite and alumina feedstocks will be required to support the aluminum industries of the U.S.S.R. and Eastern Europe.

Beyond alumina's principal use in the production of aluminum metal, the future will see an increased demand for alumina within specialty markets (abrasive, chemical, new materials, and refractory applications). Economic forecasts project that these very specialized markets will become significant profit centers for the aluminum industry of the future.

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TABLE 1
TYPICAL SPECIFICATIONS FOR GRADES OF BAUXITE

(Weight-percent, maximum content unless otherwise specified)

Constituent	Metal grade (dried Jamaica type)	Refractory grade (calcined)	Abrasive grade (calcined)
Al ₂ O ₃	¹ 47.0	¹ 86.5	¹ 83.0
SiO ₂	3.0	7.0	6.0
Fe ₂ O ₃	22.0	2.5	8.0
TiO ₂	3.0	3.75	² 3.0 - ⁴ 4.5
K ₂ O + Na ₂ O	NS	.2	.7
MgO + CaO	NS	.3	NS
CaO	NS	NS	.2
MgO	NS	NS	.4
MnO ₂ + Cr ₂ O ₃ + V ₂ O ₅	2.0	1.0	1.0
P ₂ O ₅	1.5	NS	.5
Loss on ignition	NS	.5	1.0

NS No specification.
¹Minimum content.
²Range of content.

TABLE 2
SMELTER-GRADE ALUMINA SPECIFICATIONS, IN WEIGHT-PERCENT

Impurity	Maximum content	Impurity	Maximum content
SiO ₂	0.015	B ₂ O ₃	0.001
Fe ₂ O ₃	0.015	TiO ₂	0.002
MnO	0.002	P ₂ O ₅	0.001
NiO	0.005	MgO	0.002
Cr ₂ O ₃	0.002	CaO	.04
CuO	.01	Na ₂ O	.40
V ₂ O ₅	0.002	K ₂ O	0.005
ZnO	.01	Chloride, residual	.05
Ga ₂ O ₃	.02		

Source: Industry-U.S. Bureau of Mines Alumina Miniplant Steering Committee recommended specifications, May 1979.

TABLE 3
WORLD BAUXITE RESOURCES, DECEMBER 1991

(Million metric tons of bauxite)

Continent and country	Reserves ¹	Reserve base ¹
North America and Caribbean Islands:		
Dominican Republic	30	45
Haiti	10	14
Jamaica	2,000	2,000
United States	20	40
South America:		
Brazil	2,800	2,900
Guyana	700	900
Suriname	575	600
Venezuela	320	350
Europe:		
France	10	40
Greece	600	650
Hungary	300	300
Italy	5	5
Romania	50	50
Spain	5	5
U.S.S.R.	300	300
Yugoslavia	350	400
Africa:		
Cameroon	680	1,000
Ghana	450	560
Guinea	5,600	5,900
Mozambique	2	2
Sierra Leone	140	160
Zimbabwe	2	2
Asia:		
China	400	1,450
India	1,000	1,200
Indonesia	750	805
Malaysia	15	20
Pakistan	20	20
Turkey	25	30
Oceania: Australia	5,620	7,860
Other	200	200
Total²	23,000	28,000

¹Resource Reserve Definition. Geological Survey Circular 831, 1980.

²Data may not add to totals shown because of independent rounding.

TABLE 4
SALIENT ALUMINUM STATISTICS

(Thousand metric tons and thousand dollars unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Primary production	3,343	3,944	4,030	4,048	4,121
Value	5,328,300	9,572,066	7,801,086	6,604,398	5,402,627
Price: (average cents per pound)					
U.S. market (spot)	72.3	110.1	87.8	74.0	59.5
Secondary recovery	1,986	2,122	2,054	2,393	2,501
Exports (crude and semicrude)	917	1,247	1,615	*1,659	1,762
Imports for consumption (crude and semicrude)	1,850	1,620	1,470	1,514	1,490
Aluminum industry shipments ¹	6,813	6,851	6,761	*6,569	*6,235
Consumption, apparent	5,469	5,373	4,957	*5,264	5,235
World: Production	*16,514	*17,548	*18,199	*17,977	*18,194

*Estimated. *Preliminary. *Revised.
¹Shipped to domestic industry.

TABLE 5
PRIMARY ANNUAL ALUMINUM PRODUCTION CAPACITY IN THE UNITED STATES, BY COMPANY

Company	Yearend capacity (thousand metric tons)		1991 ownership (percent)
	1990	1991	
Alcan Aluminum Corp.:			
Sebree, KY	163	163	Alcan Aluminium Ltd., 100%.
Alumax Inc.:			
Ferndale, WA (Intalco)	259	275	AMAX Inc., 75%; Mitsui & Co., 11%; Toyo Sash 7%; Yoshida Kogyo K.K., 7%.
Frederick, MD (Eastalco)	160	170	Do.
Mount Holly, SC	181	184	AMAX, 73%; Clarendon Ltd., 27%.
Total	600	629	
Aluminum Co. of America:			
Alcoa, TN	210	210	Aluminum Co. of America, 100%.
Badin, NC	115	115	Do.
Evansville, IN (Warrick)	300	300	Do.
Massena, NY	125	125	Do.
Rockdale, TX	315	315	Do.
Wenatchee, WA	220	220	Do.
Total	1,285	1,285	
Columbia Aluminum Corp.:			
Goldendale, WA	168	168	Columbia Aluminum Corp., 70%; employees, 30%.
Columbia Falls Aluminum Co.:			
Columbia Falls, MT	168	168	Montana Aluminum Investors Corp., 100%.
Kaiser Aluminum & Chemical Corp.:			
Mead, WA (Spokane)	200	200	MAXXAM Inc., 100%.
Tacoma, WA	73	73	Do.
Total	273	273	
NSA:¹			
Hawesville, KY	180	186	Southwire Co., 100%.
Noranda Aluminum Inc.:			
New Madrid, MO	204	204	Noranda Mines Ltd., 100%.
Northwest Aluminum Corp.²			
The Dalles, OR	82	82	Martin Marietta Corp., 87.2%; private interests, 12.8%.
Ormet Corp.:			
Hannibal, OH	245	245	Ohio River Associates Inc., 100%.
Ravenswood Aluminum Corp.:			
Ravenswood, WV	166	166	Stanwich Partners Inc., 100%.
Reynolds Metals Co.:			
Longview, WA	204	204	Reynolds Metals Co., 100%.
Massena, NY	123	123	Do.
Troutdale, OR	121	121	Do.
Total	448	448	
Vanalco Inc.:			
Vancouver, WA	115	116	Vanalco Inc., 100%.
Grand total	4,097	4,133	

¹Revised.

¹Southwire Co. purchased 50% from National Steel Corp. in Apr. 1990.

²Northwest Aluminum Corp. signed a lease-purchase agreement for The Dalles smelter with Martin Marietta Corp. in 1986.

TABLE 6
U.S. CONSUMPTION OF AND RECOVERY FROM PURCHASED NEW
AND OLD ALUMINUM SCRAP,¹ BY CLASS

(Metric tons)

Class	Consumption	Calculated recovery	
		Aluminum	Metallic
1990			
Secondary smelters	982,011	800,918	860,902
Primary producers	1,212,392	1,015,852	1,085,483
Fabricators	238,331	198,470	223,310
Foundries	71,626	58,893	63,531
Chemical producers	57,017	45,251	45,578
Total	2,561,377	2,119,384	2,278,804
Estimated full industry coverage	2,690,000	2,225,000	2,393,000
1991			
Secondary smelters	1,080,107	878,769	942,364
Primary producers	1,260,752	1,055,742	1,125,035
Fabricators	237,224	196,511	221,184
Foundries	77,700	64,670	69,650
Chemical producers	30,953	21,057	21,332
Total²	2,686,735	2,216,749	2,379,564
Estimated full industry coverage	2,825,000	2,329,000	2,501,000

¹Excludes recovery from other than aluminum-base scrap.

²Data may not add to totals shown because of independent rounding.

TABLE 7
U.S. STOCKS, RECEIPTS, AND CONSUMPTION OF PURCHASED NEW AND OLD ALUMINUM
SCRAP¹ AND SWEATED PIG IN 1991

(Metric tons)

Class of consumer and type of scrap	Stocks, Jan. 1	Net receipts ²	Consumption	Stocks, Dec. 31
Secondary smelters:				
New scrap:				
Solids	5,676	106,040	106,112	5,604
Borings and turnings	5,689	101,355	101,601	5,443
Dross and skimmings	3,395	41,901	43,234	2,062
Other ³	4,506	116,367	115,782	5,091
Total	<u>19,266</u>	<u>365,663</u>	<u>366,729</u>	<u>18,200</u>
Old scrap:				
Castings, sheet, clippings	16,576	407,598	406,634	17,540
Aluminum-copper radiators	576	9,934	9,741	769
Aluminum cans ⁴	6,032	242,992	241,187	7,837
Other ⁵	426	45,276	45,367	335
Total⁶	<u>23,610</u>	<u>705,800</u>	<u>702,928</u>	<u>26,481</u>
Sweated pig	956	10,121	10,449	628
Total secondary smelters⁶	<u>43,832</u>	<u>1,081,584</u>	<u>1,080,107</u>	<u>45,309</u>
Primary producers, foundries, fabricators, chemical plants:				
New scrap:				
Solids	10,823	408,067	405,716	13,174
Borings and turnings	61	26,665	26,540	186
Dross and skimmings	1,416	21,081	21,700	797
Other ³	4,148	207,072	204,100	7,120
Total	<u>16,448</u>	<u>662,885</u>	<u>658,056</u>	<u>21,277</u>
Old scrap:				
Castings, sheet, clippings	1,781	219,716	219,592	1,905
Aluminum-copper radiators	85	38,805	38,865	25
Aluminum cans	21,037	679,384	672,596	27,825
Total	<u>22,903</u>	<u>937,905</u>	<u>931,053</u>	<u>29,755</u>
Sweated pig	833	17,884	17,520	1,197
Total primary producers, etc.	<u>40,184</u>	<u>1,618,674</u>	<u>1,606,629</u>	<u>52,229</u>
All scrap consumed:				
New scrap:				
Solids	16,499	514,107	511,828	18,778
Borings and turnings	5,751	128,020	128,141	5,629
Dross and skimmings	4,811	62,982	64,934	2,859
Other	8,654	323,439	319,882	12,211
Total new scrap	<u>35,715</u>	<u>1,028,548</u>	<u>1,024,785</u>	<u>39,477</u>
Old scrap:				
Castings, sheet, clippings	18,357	627,314	626,226	19,445
Aluminum-copper radiators	661	48,739	48,606	794
Aluminum cans	27,069	922,376	913,783	35,662
Other	426	45,276	45,367	335
Total old scrap⁶	<u>46,513</u>	<u>1,643,705</u>	<u>1,633,981</u>	<u>56,236</u>

See footnotes at end of table.

TABLE 7—Continued
**U. S. STOCKS, RECEIPTS, AND CONSUMPTION OF PURCHASED NEW AND OLD ALUMINUM
 SCRAP¹ AND SWEATED PIG IN 1991**

(Metric tons)

Class of consumer and type of scrap	Stocks, Jan. 1	Net receipts ²	Consumption	Stocks, Dec. 31
Sweated pig	1,788	28,005	27,969	1,825
Total of all scrap consumed ⁶	<u>84,016</u>	<u>2,700,258</u>	<u>2,686,735</u>	<u>97,538</u>

¹Revised.

²Includes imported scrap. According to reporting companies, 3.60% of total receipts of aluminum-base scrap, or 97,228 metric tons, was received on toll arrangements.

³Includes inventory adjustment.

⁴Includes data on foil, can stock clippings, and other miscellaneous.

⁵Used beverage cans toll treated for primary producers are included in secondary smelter tabulation.

⁶Includes municipal wastes (includes litter) and fragmentized scrap (auto shredder).

⁷Data may not add to totals shown because of independent rounding.

TABLE 8
PRODUCTION AND SHIPMENTS OF SECONDARY ALUMINUM ALLOYS BY
INDEPENDENT SMELTERS IN THE UNITED STATES

(Metric tons)

	1990		1991	
	Production	Net shipments ¹	Production	Net shipments ¹
Die-cast alloys:				
13% Si, 360, etc. (0.6% Cu, maximum)	60,935	61,918	60,690	59,909
380 and variations	273,432	272,270	308,968	310,083
Sand and permanent mold:				
95/5 Al-Si, 356, etc. (0.6% Cu, maximum)	16,618	16,606	12,587	12,653
No. 12 and variations	W	W	W	W
No. 319 and variations	57,284	55,577	49,308	51,491
F-132 alloy and variations	8,693	11,279	13,770	17,294
Al-Mg alloys	695	700	723	719
Al-Zn alloys	2,648	2,489	2,761	2,789
Al-Si alloys (0.6% to 2.0% Cu)	11,896	11,906	8,608	8,420
Al-Cu alloys (1.5% Si, maximum)	1,753	1,745	1,195	1,249
Al-Si-Cu-Ni alloys	1,174	1,178	1,278	1,272
Other	1,468	1,357	890	1,006
Wrought alloys: Extrusion billets	125,604	125,937	67,922	68,827
Miscellaneous:				
Steel deoxidation	4,866	5,437	6,690	6,690
Pure (97.0% Al)	29	29	117	4,865
Aluminum-base hardeners	1,478	1,520	100	445
Other ²	34,407	34,787	29,060	27,571
Total	602,980	604,735	564,667	575,283
Less consumption of materials other than scrap:				
Primary aluminum	43,336	—	15,881	—
Primary silicon	29,127	—	26,979	—
Other	3,320	—	1,888	—
Net metallic recovery from aluminum scrap and sweated pig consumed in production of secondary aluminum ingot³	527,197	XX	519,919	XX

W Withheld to avoid disclosing company proprietary data; included with "Sand and permanent mold: Other. XX Not applicable.

¹Includes inventory adjustment.

²Includes other die-cast alloys and other miscellaneous.

³No allowance made for melt-loss of primary aluminum and alloying ingredients.

TABLE 9
U.S. APPARENT ALUMINUM SUPPLY AND CONSUMPTION
(Thousand metric tons)

	1987	1988	1989	1990	1991
Primary production	3,343	3,944	4,030	4,048	4,121
Change in stocks: ¹					
Aluminum industry	+341	+11	+61	+2	+32
LME stocks in U.S. warehouses	—	—	—	—	-168
Imports	1,850	1,620	1,470	1,514	1,490
Secondary recovery: ²					
New scrap	1,134	1,077	1,043	1,034	979
Old scrap	852	1,045	1,011	1,359	1,522
Total supply	7,520	7,697	7,615	7,957	7,976
Less total exports	917	1,247	1,615	1,659	1,762
Apparent aluminum supply available for domestic manufacturing	6,603	6,450	6,000	6,298	6,214
Apparent consumption ³	5,469	5,373	4,957	5,264	5,235

¹Revised.

²Positive figure indicates a decrease in stocks; negative figure indicates an increase in stocks.

³Metallic recovery from purchased, tolled, or imported new and old aluminum scrap expanded for full industry coverage.

⁴Apparent aluminum supply available for domestic manufacturing less recovery from purchased new scrap (a measure of consumption in manufactured end products).

TABLE 10
DISTRIBUTION OF END-USE SHIPMENTS OF ALUMINUM PRODUCTS IN THE UNITED STATES,
BY INDUSTRY

Industry	1989		1990		1991 ^P	
	Quantity (thousand metric tons)	Percent of grand total	Quantity (thousand metric tons)	Percent of grand total	Quantity (thousand metric tons)	Percent of grand total
Containers and packaging	2,112	27.0	2,157	28.0	2,210	29.1
Building and construction	1,294	16.5	1,208	15.7	1,052	13.9
Transportation	1,448	18.5	1,388	18.0	1,254	16.5
Electrical	663	8.5	594	7.7	579	7.6
Consumer durables	544	7.0	509	6.6	472	6.2
Machinery and equipment	436	5.6	452	5.9	426	5.6
Other markets	264	3.4	261	3.4	241	3.2
Total to domestic users ¹	6,761	86.5	6,569	85.3	6,235	82.1
Exports	1,060	13.5	1,131	14.7	1,357	17.9
Grand total	7,821	100.0	7,700	100.0	7,592	100.0

^PPreliminary. ^RRevised.

¹Data may not add to totals shown because of independent rounding.

Source: The Aluminum Association Inc.

TABLE 11
U.S. NET SHIPMENTS¹ OF ALUMINUM WROUGHT AND CAST
PRODUCTS, BY PRODUCERS

(Metric tons)

	1990	1991 ^P
Wrought products:		
Sheet, plate, foil	*3,798,548	3,786,362
Rod, bar, pipe, tube, and shapes	*1,210,654	1,095,508
Rod, wire, cable	*301,320	310,422
Forgings (including impacts)	*69,739	62,800
Powder, flake, paste	*44,500	44,003
Total	*5,424,761	5,299,095
Castings:		
Sand	103,873	NA
Permanent mold	208,496	NA
Die	620,641	NA
Other	34,958	NA
Total	967,968	NA
Grand total	6,392,729	NA

^PPreliminary. *Revised. NA Not available.

¹Net shipments derived by subtracting the sum of producers' domestic receipts of each mill shape from the domestic industry's gross shipments of that shape.

Source: U.S. Department of Commerce.

TABLE 12
DISTRIBUTION OF WROUGHT PRODUCTS IN THE UNITED STATES

(Percent)

	1990	1991 ^P
Sheet, plate, foil:		
Nonheat-treatable	*59.1	61.1
Heat-treatable	*3.8	3.2
Foil	*7.2	7.1
Rod, bar, pipe, tube, shapes:		
Rod and bar (rolled and extruded)	*1.2	1.3
Pipe and tube (extruded and drawn)	2.4	2.5
Extruded shapes	*18.7	17.0
Rod, wire, cable:		
Rod and bare wire	*1.0	0.9
Cable and insulated wire	*4.5	4.9
Forgings (including impacts)	1.3	1.2
Powder, flake, paste	0.8	0.8
Total	100.0	100.0

^PPreliminary. *Revised.

Source: U.S. Department of Commerce.

**TABLE 13
AVERAGE PRIMARY ALUMINUM METAL PRICES**

(Cents per pound)

	COMEX 1 ¹	COMEX 2 ¹	COMEX 3 ¹	LME-cash (high grade)	U.S. market	U.S. transaction
1990: Annual average	<u>73.42</u>	<u>73.67</u>	<u>73.92</u>	<u>74.37</u>	<u>74.04</u>	<u>75.00</u>
1991:						
January	72.00	72.00	72.00	68.73	68.57	69.38
February	68.45	68.45	68.45	68.25	68.13	68.89
March	68.50	68.50	68.50	67.86	68.31	68.98
April	68.50	68.50	68.50	63.13	63.88	64.41
May	63.59	63.59	63.59	58.79	59.32	59.56
June	60.60	60.60	60.60	57.84	57.75	58.56
July	59.50	59.50	59.50	58.82	58.96	59.68
August	59.09	59.09	59.09	56.99	57.66	57.83
September	57.15	57.15	57.15	54.97	55.75	56.02
October	53.57	53.57	53.57	52.17	52.46	53.23
November	56.95	56.95	56.95	51.47	52.41	52.49
December	52.79	52.79	52.79	49.78	50.35	50.61
Annual average	<u>61.72</u>	<u>61.72</u>	<u>61.72</u>	<u>59.07</u>	<u>59.46</u>	<u>59.97</u>

¹COMEX delivery positions: 1—within 1 month; 2—within 3 months; and 3—within 12 months.

Source: Metals Week.

**TABLE 14
U.S. EXPORTS OF ALUMINUM, BY CLASS**

Class	1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Crude and semicrude:				
Metals and alloys, crude	7684,150	\$1,169,398	792,794	\$1,274,285
Scrap	537,312	719,041	460,820	541,702
Plates, sheets, bars, strip, etc.	419,275	1,277,799	488,950	1,383,928
Castings and forgings	7,004	67,981	7,336	90,288
Semifabricated forms, n.e.c.	11,385	60,718	12,387	65,862
Total ¹	<u>7,659,124</u>	<u>\$3,294,938</u>	<u>1,762,287</u>	<u>3,356,065</u>
Manufactures:				
Foil and leaf	26,612	92,424	35,373	116,975
Powders and flakes	4,702	19,333	4,494	18,291
Wire and cable	5,765	22,964	22,314	65,739
Total ¹	<u>37,079</u>	<u>134,721</u>	<u>62,181</u>	<u>201,005</u>
Grand total ¹	<u>7,696,203</u>	<u>\$3,429,659</u>	<u>1,824,468</u>	<u>3,557,070</u>

¹Revised.

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 15
U.S. EXPORTS OF ALUMINUM, BY COUNTRY

Country	Metals and alloys, crude		Plates, sheets, bars, etc. ¹		Scrap		Total ²	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1990:								
Brazil	173	\$1,495	5,759	\$27,272	3,047	\$4,243	8,979	\$33,010
Canada	^{74,958}	^{144,668}	267,909	735,779	49,674	62,677	^{392,540}	^{943,124}
France	^{8,233}	15,253	4,243	27,410	13,817	15,347	^{26,293}	58,010
Germany	3,710	8,417	5,604	27,351	5,521	7,905	14,836	43,673
Hong Kong	2,051	3,444	3,578	11,474	1,517	1,868	7,146	16,786
Italy	20	215	5,540	32,574	4,215	4,906	9,775	37,695
Japan	^{455,349}	^{789,755}	16,247	65,265	334,034	482,460	^{805,631}	^{1,337,480}
Korea, Republic of	39,309	42,161	12,448	45,661	23,351	28,426	75,108	116,247
Mexico	^{24,839}	^{49,026}	43,610	152,677	20,802	23,314	^{89,251}	^{225,016}
Netherlands	^{13,433}	^{24,923}	2,965	14,819	7,344	10,483	^{23,742}	^{50,225}
Philippines	2,750	4,730	302	1,874	918	735	3,970	7,339
Saudi Arabia	92	428	8,852	22,929	—	—	8,944	23,357
Singapore	2,828	5,086	1,233	6,854	325	438	4,385	12,379
Taiwan	^{35,076}	^{46,451}	13,198	38,862	^{55,907}	^{56,795}	^{104,181}	^{142,108}
Thailand	^{14,095}	^{16,389}	2,826	7,406	1,263	2,365	^{18,184}	^{26,160}
U.S.S.R.	—	—	36	292	—	—	36	292
United Kingdom	564	^{2,020}	10,522	57,426	2,059	2,163	13,145	^{61,609}
Venezuela	38	127	7,707	21,265	93	99	7,838	21,492
Other	^{6,631}	^{14,810}	25,082	109,308	13,428	14,819	^{45,141}	^{138,936}
Total ²	^{684,150}	^{1,169,398}	<u>437,662</u>	<u>1,406,498</u>	<u>537,312</u>	<u>719,041</u>	<u>1,659,124</u>	<u>3,294,938</u>
1991:								
Brazil	102	297	4,871	17,299	3,832	4,163	8,804	21,758
Canada	59,736	104,828	251,778	660,989	43,082	47,752	354,596	813,570
France	8,257	12,896	3,554	20,051	9,796	9,955	21,607	42,902
Germany	302	913	8,528	35,601	2,208	2,589	11,037	39,104
Hong Kong	5,262	7,629	10,726	28,960	3,958	2,767	19,947	39,356
Italy	543	1,095	3,693	23,889	985	1,328	5,221	26,312
Japan	613,306	970,413	22,273	75,964	254,926	329,310	890,505	1,375,688
Korea, Republic of	21,498	31,652	18,306	55,498	32,926	35,470	72,730	122,619
Mexico	33,869	61,971	47,764	169,430	24,578	25,968	106,211	257,369
Netherlands	2,054	4,252	3,379	17,461	1,753	2,558	7,186	24,271
Philippines	4,504	6,930	142	486	178	382	4,824	7,798
Saudi Arabia	88	338	26,650	64,995	—	—	26,738	65,333
Singapore	981	1,496	2,423	7,786	812	964	4,216	10,246
Taiwan	24,804	37,350	16,491	57,835	65,157	58,803	106,452	153,989
Thailand	7,833	11,095	9,114	19,287	2,126	3,120	19,073	33,502
U.S.S.R.	3	9	52	373	—	—	55	383
United Kingdom	1,882	4,338	11,304	55,856	3,356	3,671	16,542	63,864
Venezuela	5	8	18,393	57,146	4	4	18,403	57,158
Other	7,765	16,776	49,232	171,171	11,143	12,896	68,140	200,842
Total ²	<u>792,794</u>	<u>1,274,285</u>	<u>508,673</u>	<u>1,540,078</u>	<u>460,820</u>	<u>541,702</u>	<u>1,762,287</u>	<u>3,356,065</u>

¹Revised.

²Includes castings, forgings, and unclassified semifabricated forms.

³Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 16
U.S. IMPORT DUTIES FOR SELECTED ALUMINUM PRODUCTS

	HTS No.	Most favored nation (MFN)	Non-MFN
		Jan. 1, 1991	Jan. 1, 1991
Unwrought metal (in coils)	7601.10.30	2.6% ad valorem	18.5% ad valorem.
	7601.20.30	do.	Do.
Unwrought (other than Si-Al alloys)	7601.10.60	Free	11% ad valorem.
	7601.20.90	do.	10.5% ad valorem.
Waste and scrap	7602.00.00	Free	Free.

TABLE 17
U.S. IMPORTS FOR CONSUMPTION OF ALUMINUM, BY CLASS

Class	1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Crude and semicrude:				
Metals and alloys, crude	959,617	\$1,596,886	1,024,732	\$1,428,420
Plates, sheets, strip, etc., n.e.c. ¹	320,599	774,442	243,492	564,548
Pipes, tubes, etc.	3,778	26,140	3,345	27,650
Rods and bars	15,958	42,631	9,647	28,118
Scrap	214,196	259,674	208,384	219,558
Total²	1,514,147	2,699,773	1,489,600	2,268,296
Manufactures:				
Foil and leaf ³	32,974	124,505	27,488	108,318
Flakes and powders	1,484	4,305	1,057	3,116
Wire	10,898	27,757	14,742	31,539
Total	45,356	156,567	43,287	142,973
Grand total²	1,559,503	2,856,340	1,532,886	2,411,269

¹Revised.

²Includes plates, sheets, circles, and disks.

³Data may not add to totals shown because of independent rounding.

⁴Excludes etched capacitor foil.

Source: Bureau of the Census.

TABLE 18
U.S. IMPORTS FOR CONSUMPTION OF ALUMINUM, BY COUNTRY

Country	Metals and alloys, crude		Plates, sheets, bars, etc. ¹		Scrap		Total ²	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1990:								
Argentina	3,496	\$5,865	2,874	\$5,585	82	\$108	6,451	\$11,558
Australia	6,119	10,445	135	667	62	107	6,316	11,219
Bahrain	—	—	16,063	34,397	—	—	16,063	34,397
Belgium	(³)	14	19,234	46,407	—	—	19,234	46,421
Brazil	38,657	62,566	7,800	15,696	274	504	46,731	78,766
Canada	824,899	1,363,000	145,452	324,006	163,536	207,227	1,133,887	1,894,233
France	193	1,539	11,446	39,082	5	21	11,643	40,641
Germany	447	7,459	13,667	51,922	421	677	14,536	60,058
Italy	21	1,032	1,909	6,187	34	38	1,963	7,257
Japan	415	944	38,590	108,240	65	235	39,071	109,419
Korea, Republic of	6	25	152	1,034	18	19	176	1,078
Mexico	821	1,373	3,931	10,948	28,830	27,747	33,582	40,068
Netherlands	1,203	1,804	4,088	16,944	156	128	5,447	18,877
Norway	92	667	1,377	2,589	—	—	1,469	3,257
South Africa, Republic of	1,745	2,846	8,328	18,023	127	148	10,200	21,017
Spain	145	295	2,337	5,746	69	95	2,550	6,137
U.S.S.R.	—	—	23	249	2,627	3,766	2,650	4,015
United Arab Emirates	2,820	5,193	—	—	—	—	2,820	5,193
United Kingdom	351	1,865	5,924	27,634	690	748	6,965	30,247
Venezuela	76,179	126,907	20,734	37,768	8,652	10,021	105,565	174,696
Yugoslavia	127	234	16,895	32,679	—	—	17,023	32,913
Other	1,880	2,813	19,375	57,409	8,549	8,085	29,804	68,307
Total²	959,617	1,596,886	340,334	843,213	214,196	259,674	1,514,147	2,699,773
1991:								
Argentina	3,867	5,027	552	1,193	—	—	4,419	6,220
Australia	1,461	2,637	9	111	337	331	1,807	3,079
Bahrain	—	—	4,106	8,627	—	—	4,106	8,627
Belgium	1	34	11,299	26,999	921	1,054	12,220	28,087
Brazil	5,883	9,522	708	1,571	—	—	6,591	11,094
Canada	958,831	1,328,780	137,385	270,478	153,769	173,036	1,249,985	1,772,294
France	150	1,595	8,603	28,934	3,010	2,404	11,763	32,933
Germany	689	4,492	12,695	53,352	923	1,352	14,306	59,196
Italy	27	1,628	1,593	4,703	—	—	1,620	6,330
Japan	358	703	21,635	70,760	102	385	22,095	71,848
Korea, Republic of	32	127	151	1,179	—	—	183	1,307
Mexico	145	216	3,093	9,113	27,230	22,885	30,468	32,215
Netherlands	—	—	4,250	17,225	1,205	1,472	5,455	18,696
Norway	128	939	784	1,835	—	—	912	2,774
South Africa, Republic of	685	1,427	2,768	5,701	—	—	3,453	7,128
Spain	1	2	3,520	7,378	116	119	3,637	7,499
U.S.S.R.	—	—	—	—	816	1,038	816	1,038
United Arab Emirates	2,704	4,051	558	710	—	—	3,262	4,761
United Kingdom	522	1,608	5,489	23,285	2,391	2,592	8,402	27,484
Venezuela	48,865	65,141	15,852	28,154	7,560	6,140	72,277	99,435

See footnotes at end of table.

TABLE 18—Continued
U.S. IMPORTS FOR CONSUMPTION OF ALUMINUM, BY COUNTRY

Country	Metals and alloys, crude		Plates, sheets, bars, etc. ¹		Scrap		Total ²	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Yugoslavia	—	—	9,980	19,864	—	—	9,980	19,864
Other	383	489	11,455	39,146	10,005	6,752	21,844	46,387
Total²	1,024,732	1,428,420	256,484	620,317	208,384	219,558	1,489,600	2,268,296

¹Includes circles, disks, rods, pipes, tubes, etc.

²Data may not add to totals shown because of independent rounding.

³Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 19
ALUMINUM: WORLD ANNUAL PRIMARY METAL PRODUCTION
CAPACITY, BY COUNTRY¹

(Thousand metric tons)

Continent and country	1989	1990	1991 ^P
North America:			
Canada	1,594	1,594	1,835
Mexico	66	66	66
United States	4,016	4,097	4,133
South America:			
Argentina	160	160	160
Brazil	869	976	1,156
Suriname	30	30	30
Venezuela	590	610	610
Europe:			
Austria	92	92	92
Czechoslovakia	60	60	60
France	346	346	472
Germany, Federal Republic of:			
Eastern states	55	55	55
Western states	713	713	713
Greece	150	150	150
Hungary	78	78	78
Iceland	86	86	86
Italy	276	276	246
Netherlands	266	266	266
Norway	851	851	851
Poland	48	48	48
Romania	250	250	250
Spain	344	344	344
Sweden	91	91	91
Switzerland	72	72	72
U.S.S.R.	2,640	2,740	2,740
United Kingdom	287	287	287
Yugoslavia	337	342	347
Africa:			
Cameroon	80	80	80
Egypt	170	170	170
Ghana	200	200	200
South Africa, Republic of	172	172	172
Asia:			
Bahrain	205	205	225
China	875	935	1,115
India	472	472	611
Indonesia	225	225	225
Iran	50	50	50
Japan	64	64	64
Korea, North	20	—	—
Korea, Republic of	18	18	18
Taiwan	50	—	—

See footnotes at end of table.

TABLE 19—Continued
**ALUMINUM: WORLD ANNUAL PRIMARY METAL PRODUCTION
 CAPACITY, BY COUNTRY¹**

(Thousand metric tons)

Continent and country	1989	1990	1991 ^P
Asia—Continued:			
Turkey	60	60	60
United Arab Emirates: Dubai	170	170	240
Oceania:			
Australia	1,188	1,240	1,240
New Zealand	250	259	259
Total	18,636	19,000	19,967

^PPreliminary. ^RRevised.

¹Detailed information on the individual aluminum reduction plants is available in a two-part report that can be ordered from Aluminum Specialist, U.S. Bureau of Mines, 810 7th Street NW, MS #5208, Washington, DC 20241. Part 1 of "Primary Aluminum Plants, Worldwide" details location, ownership, and production capacity for 1988-95 and sources of energy for foreign and domestic primary aluminum plants, including those in centrally planned economies. Part 2 summarizes production capacities for 1988-95 by smelter and country.

TABLE 20
ALUMINUM, PRIMARY: WORLD PRODUCTION,¹ BY COUNTRY

(Thousand metric tons)

Country	1987	1988	1989	1990	1991*
Argentina	153	154	¹ 162	¹ 166	165
Australia	1,004	1,150	1,244	1,234	² 1,235
Austria	93	95	93	89	² 80
Bahrain	180	183	187	² 113	210
Brazil	843	874	890	931	² 1,140
Cameroon	79	87	92	² 93	² 89
Canada	1,540	1,534	1,555	¹ 1,567	1,830
China*	615	710	² 850	850	860
Czechoslovakia*	⁶ 68	⁶ 67	⁶ 69	⁷ 70	68
Egypt	179	173	180	179	² 178
France	323	328	335	326	² 286
Germany, Federal Republic of:					
Eastern states*	⁶ 68	61	54	² 21	NA
Western states	⁷ 793	⁷ 753	⁷ 734	⁷ 715	NA
Total*	861	814	788	736	² 690
Ghana	150	161	169	174	175
Greece ³	127	151	¹ 145	150	² 152
Hungary	76	75	75	75	² 64
Iceland	85	82	² 88	88	² 89
India ³	265	375	423	433	440
Indonesia ³	202	185	197	186	² 173
Iran*	45	40	45	² 59	² 67
Italy	233	² 226	219	232	² 218
Japan ⁴	41	35	35	34	² 32
Korea, North*	10	10	10	—	—
Korea, Republic of ⁵	22	18	18	² 2	2
Mexico ³	60	68	72	68	² 51
Netherlands	276	278	279	² 270	² 264
New Zealand	252	264	258	² 260	² 259
Norway	853	864	863	845	² 833
Poland ⁵	48	48	48	² 46	45
Romania ⁶	260	265	269	¹ 168	² 158
South Africa, Republic of	171	170	166	² 170	170
Spain	341	323	352	355	² 355
Suriname	2	10	28	² 28	28
Sweden	81	99	97	96	² 97
Switzerland	73	72	71	72	² 66
Turkey	42	57	62	⁶ 61	² 56
U.S.S.R.*	2,400	2,400	2,400	2,200	2,000
United Arab Emirates: Dubai	155	162	168	¹ 174	² 239
United Kingdom	294	300	297	290	² 294
United States	3,343	3,944	4,030	4,048	² 4,121

See footnotes at end of table.

TABLE 20—Continued
ALUMINUM, PRIMARY: WORLD PRODUCTION,¹ BY COUNTRY

(Thousand metric tons)

Country	1987	1988	1989	1990	1991 ^a
Venezuela	428	437	540	590	600
Yugoslavia ^b	244	260	331	349	315
Total	16,514	17,548	18,199	17,977	18,194

^aEstimated. ^bRevised. NA Not available.

¹The U.S. Bureau of Mines defines primary aluminum as "The weight of liquid aluminum as tapped from pots, excluding the weight of any alloying materials as well as that of any metal produced from either returned scrap or remelted materials." International reporting practices vary from country to country, some nations conforming to the foregoing definition and others using different definitions. For those countries for which a different definition is given specifically in the source publication, that definition is provided in this table by footnote. Table includes data available through May 27, 1992.

²Reported figure.

³Primary ingot.

⁴Excludes high-purity aluminum containing 99.995% or more as follows, in metric tons: 1987—12,099; 1988—13,628; 1989—15,696; 1990—16,292; and 1991—19,652.

⁵Primary unalloyed ingot plus secondary unalloyed ingot.

⁶Primary unalloyed metal plus primary alloyed metal, thus including weight of alloying material.

⁷Data do not add to total shown because of independent rounding.

TABLE 21
SALIENT BAUXITE STATISTICS

(Thousand metric tons and thousand dollars)

	1987	1988	1989	1990	1991
United States:					
Production: Crude ore (dry equivalent)	576	588	W	W	W
Value*	\$10,916	\$10,566	W	W	W
Exports (as shipped)	201	63	44	53	51
Imports for consumption ¹	9,156	9,944	10,893	12,142	11,793
Consumption (dry equivalent)	9,548	10,074	11,810	12,042	12,204
World: Production	² 91,601	² 96,957	² 104,081	² 109,601	² 109,172

*Estimated. ¹Revised. W Withheld to avoid disclosing company proprietary data.

²Excludes calcined bauxite. Includes bauxite imported to the U.S. Virgin Islands.

TABLE 22
PRODUCTION AND SHIPMENTS OF ALUMINA IN THE UNITED STATES

(Thousand metric tons)

Year	Calcined alumina	Other alumina ²	Total ¹	
			As produced or shipped ³	Calcined equivalent
Production:⁴				
1987	3,555	830	4,385	4,150
1988	4,185	810	4,995	4,770
1989	4,580	605	5,180	5,000
1990	4,775	655	5,430	5,230
1991	4,805	610	5,415	5,230
Shipments:⁴				
1987	3,530	845	4,375	4,135
1988	4,945	815	5,760	5,535
1989	4,665	605	5,270	5,090
1990	4,750	575	5,325	5,150
1991	4,865	630	5,500	5,305

⁴Estimated.

¹Data may not add to totals shown because of independent rounding.

²Trihydrate, activated, tabular, and other aluminas. Excludes calcium and sodium aluminates.

³Includes only the end product if one type of alumina was produced and used to make another type of alumina.

TABLE 23
CAPACITIES OF DOMESTIC ALUMINA PLANTS,¹ DECEMBER 31

(Thousand metric tons per year)

Company and plant	1989	1990	1991
Aluminum Co. of America:			
Bauxite, AR	340	—	—
Point Comfort, TX	1,735	1,735	1,735
Total	2,075	1,735	1,735
Kaiser Aluminum & Chemical Corp.:			
Gramercy, LA	795	1,000	1,000
Ormet Corp.: Burnside, LA	545	545	545
Reynolds Metals Co.: Corpus Christi, TX	1,700	1,700	1,700
Virgin Islands Alumina: St. Croix, VI	—	635	635
Grand total	5,115	5,615	5,615

¹Capacity may vary depending on the bauxite used.

TABLE 24
U.S. CONSUMPTION OF BAUXITE, BY INDUSTRY

(Thousand metric tons, dry equivalent)

Industry	Domestic	Foreign	Total
1990:			
Alumina	W	¹ 10,757	11,064
Abrasive ²	W	W	276
Chemical	W	W	212
Refractory	W	³ 679	³ 387
Other	W	W	103
Total	606	¹11,436	¹12,042
1991:			
Alumina	W	¹ 11,547	11,383
Abrasive ²	W	W	204
Chemical	W	W	218
Refractory	W	³ 595	328
Other	W	W	71
Total	62	12,142	12,204

¹Revised. W Withheld to avoid disclosing company proprietary data; included in "Total."

²Includes "Abrasive."

³Includes consumption by Canadian abrasive industry.

⁴Includes "Chemical" and "Other."

TABLE 25
U.S. CONSUMPTION OF CRUDE AND PROCESSED BAUXITE

(Thousand metric tons, dry equivalent)

Type	Domestic origin	Foreign origin	Total
1990:			
Crude and dried	W	W	11,357
Calcined and activated	W	W	685
Total	606	11,436	12,042
1991:			
Crude and dried	W	W	11,668
Calcined and activated	W	W	536
Total	62	12,142	12,204

¹Revised. W Withheld to avoid disclosing company proprietary data; included in "Total."

TABLE 26
PRODUCTION AND SHIPMENTS OF SELECTED ALUMINUM SALTS
IN THE UNITED STATES IN 1990

Item	Number of producing plants	Production (thousand metric tons)	Total shipments, including interplant transfers	
			Quantity (thousand metric tons)	Value (thousands)
Aluminum sulfate:				
Commercial and municipal (17% Al ₂ O ₃)	75	1,113	1,054	\$135,063
Iron-free (17% Al ₂ O ₃)	21	115	110	14,467
Aluminum chloride:				
Liquid and crystal	3	W	W	W
Anhydrous (100% AlCl ₃)	3	W	W	W
Aluminum fluoride, technical	2	W	W	W
Aluminum hydroxide, trihydrate [100% Al(OH) ₃]	9	725	701	234,198
Aluminates	17	95	89	29,033
Other aluminum compounds ¹	XX	XX	XX	147,366

W Withheld to avoid disclosing company proprietary data. XX Not applicable.

¹Includes light aluminum hydroxide, cryolite, etc.

Source: Data are based on Bureau of the Census 1990 Current Industrial Reports, Series MA-28A, "Inorganic Chemicals."

TABLE 27
STOCKS OF BAUXITE IN THE
UNITED STATES,¹ DECEMBER 31

(Thousand metric tons, dry equivalent)

Sector	1990	1991
Producers, processors, and consumers	2,318	2,643
Government	18,477	18,477
Total	20,795	21,120

¹Revised.

¹Domestic and foreign bauxite; crude, dried, calcined, activated; all grades.

TABLE 28
STOCKS OF ALUMINA IN THE
UNITED STATES,¹ DECEMBER 31

(Thousand metric tons, calcined equivalent)

Sector	1990	1991
Producers	679	582
Primary aluminum plants	1,419	1,315
Total	2,098	1,897

¹Estimated.

¹Excludes consumers' stocks other than those at primary aluminum plants.

TABLE 29
AVERAGE VALUE OF U.S. IMPORTS OF CRUDE AND DRIED
BAUXITE¹

(Per metric ton)

Country	1990		1991	
	Port of shipment (f.a.s.)	Delivered to U.S. ports (c.i.f.)	Port of shipment (f.a.s.)	Delivered to U.S. ports (c.i.f.)
Australia	\$16.31	\$27.14	\$19.48	\$31.25
Brazil	32.48	41.17	32.11	38.65
Guinea	33.08	40.25	32.44	39.64
Guyana	29.20	39.34	30.48	39.14
Jamaica	25.07	29.67	29.57	34.83
Weighted average	27.23	35.51	28.82	36.70

¹Computed from quantity and value data reported to U.S. Customs Service and compiled by the Bureau of the Census, U.S. Department of Commerce. Not adjusted for moisture content of bauxite or differences in methods used by importers to determine value of individual shipments.

TABLE 30
**MARKET QUOTATIONS ON ALUMINA AND ALUMINUM
 COMPOUNDS**

(Per metric ton, in bags, carlots, freight equalized)

Compound	Dec. 28, 1990	Dec. 27, 1991
Alumina, calcined	\$418.88	\$418.88
Alumina, hydrated, bulk	278.88	278.88
Alumina, activated, granular, works	904.99	904.99
Aluminum sulfate, commercial, ground, (17% Al ₂ O ₃)	253.53	253.53
Aluminum sulfate, iron-free, dry (17% Al ₂ O ₃)	358.25	358.25

Source: Chemical Marketing Reporter.

TABLE 31
U.S. EXPORTS OF ALUMINA,¹ BY COUNTRY

(Thousand metric tons, calcined equivalent, and thousand dollars)

Country	1989		1990		1991	
	Quantity	Value	Quantity	Value	Quantity	Value
Argentina	1	849	(²)	440	1	837
Belgium	5	5,292	5	5,365	2	3,562
Brazil	20	6,966	¹ 123	³ 31,445	186	34,592
Canada	942	257,466	709	197,889	753	205,810
Finland	(²)	281	(²)	278	77	17,615
France	3	2,225	1	3,523	1	2,526
Germany, Federal Republic of	2	7,216	3	12,702	1	8,460
Ghana	125	22,579	83	² 20,770	98	22,298
Japan	23	19,842	12	¹ 15,573	22	13,300
Mexico	150	56,280	170	66,215	125	47,388
Netherlands	8	9,709	¹ 19	9,972	13	7,817
Norway	—	—	27	8,521	—	—
Sweden	27	5,634	62	18,553	12	2,933
U.S.S.R.	—	—	29	8,828	35	10,181
United Kingdom	2	4,471	2	4,249	2	4,723
Venezuela	² 2	2,008	3	2,789	4	3,865
Other	17	¹ 19,105	¹ 15	¹ 18,600	19	22,460
Total	³1,328	¹419,923	¹1,263	¹425,712	1,351	408,367

¹Revised.

¹Includes exports of aluminum hydroxide (calcined equivalent) as follows: 1989—33,316 tons; 1990—34,124 tons; and 1991—35,105 tons.

²Less than 1/2 unit.

³Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 32
U.S. IMPORTS FOR
CONSUMPTION OF BAUXITE, CRUDE AND DRIED,¹
BY COUNTRY

(Thousand metric tons)

Country	1989	1990	1991
Australia	1,535	1,430	408
Brazil	1,373	1,812	1,905
China	69	47	93
Guinea	3,504	3,669	3,609
Guyana	379	546	1,137
India	—	—	105
Indonesia	306	413	135
Jamaica ²	3,330	3,886	4,261
Malaysia	172	129	63
Sierra Leone	167	159	—
Other	58	51	75
Total	10,893	12,142	³11,793

¹Includes bauxite imported to the U.S. Virgin Islands from foreign countries.

²Dry equivalent of shipments to the United States.

³Data do not add to total shown because of independent rounding.

Note.—Total U.S. imports of crude and dried bauxite (including the U.S. Virgin Islands) as reported by the Bureau of the Census were as follows: 1989—11,346,182 tons; 1990—12,628,163 tons; and 1991—11,174,990 tons.

Source: Bureau of the Census and the Jamaica Bauxite Institute.

TABLE 33
U.S. IMPORTS FOR CONSUMPTION OF CALCINED BAUXITE, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1990				1991			
	Refractory grade		Other grade		Refractory grade		Other grade	
	Quantity	Value ¹	Quantity	Value ¹	Quantity	Value ¹	Quantity	Value ¹
Australia	—	—	¹ 14	1,100	—	—	16	1,247
China	126	8,097	173	10,089	104	6,492	96	5,951
Guinea	—	—	78	⁵ 5,004	—	—	—	—
Guyana	84	9,273	52	2,372	69	7,271	47	2,214
Malaysia	—	—	2	¹ 182	—	—	31	1,364
Other	(²)	9	28	1,079	7	440	5	219
Total³	210	17,379	348	¹19,826	181	14,203	195	10,995

¹Revised.

²Value at foreign port of shipment as reported to U.S. Customs Service.

³Less than 1/2 unit.

⁴Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census, data adjusted by the U.S. Bureau of Mines.

TABLE 34
U.S. IMPORTS FOR CONSUMPTION OF ALUMINA,¹ BY COUNTRY

(Thousand metric tons, calcined equivalent, and thousand dollars)

Country	1989		1990		1991	
	Quantity	Value ²	Quantity	Value ²	Quantity	Value ²
Australia	3,603	915,113	3,413	949,280	3,639	792,056
Brazil	44	21,465	86	26,515	92	20,520
Canada	153	69,711	123	56,021	74	39,790
France	5	13,369	5	13,428	7	15,537
Germany, Federal Republic of	20	30,576	23	37,550	20	36,752
India	35	8,916	(³)	15	72	19,376
Italy	(³)	386	(³)	531	(³)	489
Jamaica	218	92,144	173	100,762	394	102,126
Japan	9	13,109	8	13,424	8	13,557
Suriname	209	52,124	173	45,424	242	47,784
Venezuela	1	136	1	382	(³)	41
Other	15	11,075	64	25,640	44	13,979
Total⁴	4,312	1,228,123	4,069	1,268,973	4,592	1,102,008

¹Revised.

²Includes imports of aluminum hydroxide.

³Value at foreign port of shipment as reported to U.S. Customs Service.

⁴Less than 1/2 unit.

⁵Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 35
BAUXITE: WORLD PRODUCTION, BY COUNTRY¹

(Thousand metric tons)

Country	1987	1988	1989	1990	1991 ²
Albania ³	¹ 35	38	35	² 26	² 8
Australia	34,102	36,192	38,583	¹ 41,391	² 40,503
Brazil	6,567	8,083	8,665	⁹ 6,678	² 10,310
China ⁴	² 2,200	² 2,300	² 2,388	² 2,400	2,600
Dominican Republic ³	187	168	151	⁸ 5	7
France	1,271	978	720	⁶ 636	² 183
Ghana	196	285	347	381	400
Greece	² 2,467	² 2,433	² 2,602	² 2,504	² 2,130
Guinea ⁴	13,500	15,619	16,523	¹ 17,524	² 17,054
Guyana ³	2,785	1,774	1,321	¹ 1,424	² 2,204
Hungary	3,101	2,593	2,644	² 2,559	² 2,037
India	2,779	3,961	4,768	⁴ 4,852	² 4,835
Indonesia	635	513	862	1,206	² 1,242
Italy	17	17	12	¹ (⁵)	9
Jamaica ^{3 6}	7,802	7,305	9,601	10,921	² 11,552
Malaysia	482	361	355	398	² 376
Mozambique	5	7	6	7	8
Pakistan	3	2	2	³	3
Romania ⁴	⁵ 480	⁵ 500	² 313	² 204	200
Sierra Leone	1,390	1,379	1,562	¹ 1,430	² 1,288
Spain	1	3	³	³	3
Suriname	2,522	3,434	3,530	3,267	² 3,198
Turkey ⁷	259	269	⁵ 534	⁷ 779	530
U.S.S.R. ⁸	4,600	4,600	4,600	4,200	3,800
United States ³	576	588	W	W	W
Venezuela	245	522	702	771	² 1,992
Yugoslavia	3,394	3,034	3,252	2,952	2,700
Total	⁹ 1,601	⁹ 6,957	¹ 04,081	¹ 09,601	109,172

¹Estimated. ²Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

³Table includes data available through June 16, 1992.

⁴Reported figure.

⁵Dry bauxite equivalent of crude ore.

⁶Dry bauxite equivalent of ore processed by drying plant.

⁷Less than 1/2 unit.

⁸Bauxite processed for conversion to alumina in Jamaica plus kiln-dried ore prepared for export.

⁹Public-sector production only.

¹⁰In addition to the bauxite reported in the body of the table, the U.S.S.R. produces nepheline syenite concentrates and alunite ore as sources of aluminum. Nepheline syenite concentrate production was as follows, in thousand metric tons: 1987—1,660; 1988—1,639; 1989—1,697; 1990—1,650 (estimated); and 1991—1,500 (estimated). Estimated alunite ore production was as follows, in thousand metric tons: 1987—625; 1988—625; 1989—600; 1990—550; and 1991—500. Nepheline syenite concentrate grades 25% to 30% alumina, and alunite ore grades 16% to 18% alumina; these commodities may be converted to their bauxite equivalent by using factors of 1 ton of nepheline syenite concentrate equals 0.55 ton of bauxite and 1 ton of alunite equals 0.34 ton of bauxite.

TABLE 36
WORLD ANNUAL ALUMINA CAPACITY, BY COUNTRY

(Thousand metric tons, yearend)

Country	1988	1989	1990	1991
Australia	10,000	10,850	11,700	11,850
Brazil	1,150	1,555	1,555	1,750
Canada	1,225	1,140	1,140	1,150
China	1,500	1,500	1,700	1,700
Czechoslovakia	210	210	210	210
France	1,040	700	700	700
Germany, Federal Republic of:				
Eastern states	60	60	—	—
Western states	1,745	1,380	1,170	1,170
Greece	500	600	600	600
Guinea	700	700	700	700
Guyana	355	300	—	—
Hungary	920	920	920	920
India	1,000	1,580	1,580	1,610
Ireland	800	900	1,000	1,000
Italy	720	720	820	850
Jamaica	3,100	2,950	2,950	3,250
Japan	550	500	500	500
Romania	540	540	540	540
Spain	800	1,000	1,000	1,000
Suriname	1,350	1,400	1,500	1,500
Turkey	200	200	200	200
U.S.S.R.	4,600	4,600	4,600	4,600
United Kingdom	120	120	120	120
United States	5,115	5,115	5,615	5,615
Venezuela	1,300	1,300	1,300	1,300
Yugoslavia	1,635	1,570	1,570	1,380
Total	41,235	42,410	43,690	44,215

TABLE 37
ALUMINA: WORLD PRODUCTION,¹ BY COUNTRY²

(Thousand metric tons)

Country	1987	1988	1989	1990	1991 ³
Australia	10,109	10,511	10,800	11,231	³ 11,713
Brazil	1,326	1,488	1,632	¹ 1,655	1,600
Canada	953	993	1,048	1,087	³ 1,131
China ⁴	1,200	¹ 1,300	¹ 1,350	1,500	1,600
Czechoslovakia	134	138	² 205	² 175	150
France	711	563	480	² 464	² 403
Germany, Federal Republic of:					
Eastern states	51	64	⁶ 60	⁵ 50	NA
Western states	1,313	1,163	1,174	¹ 1,173	NA
Total	1,364	1,227	1,234	² 1,223	1,165
Greece	518	515	521	⁵ 530	520
Guinea	543	589	619	⁶ 642	³ 632
Hungary	858	803	882	826	³ 546
India	650	1,188	¹ 1,947	¹ 1,601	1,700
Ireland	784	843	891	⁸ 885	900
Italy ⁴	700	708	722	⁷ 752	760
Jamaica	¹ 1,609	¹ 1,514	2,221	2,869	³ 3,015
Japan ⁵	358	415	466	⁴ 481	⁴ 438
Romania	584	620	611	⁴ 440	400
Spain ⁴	801	⁸ 880	949	¹ 1,002	950
Suriname	1,363	1,632	1,567	1,532	³ 1,510
Turkey	95	182	201	¹ 177	159
U.S.S.R. ⁶	3,500	3,500	3,500	3,300	3,000
United Kingdom	110	114	116	¹ 120	110
United States ⁶	4,150	4,770	5,000	5,230	5,230
Venezuela	1,360	1,284	1,212	1,293	³ 1,295
Yugoslavia	1,113	1,051	¹ 1,170	¹ 1,086	900
Total ⁶	³ 34,893	³ 36,826	³ 39,345	² 40,101	39,827

⁶Estimated. ⁷Revised. NA Not available.

¹Figures represent calcined alumina or the total of calcined alumina plus the calcined equivalent of hydrate, when available; exceptions, if known, are noted.

²Table includes data available through June 16, 1992.

³Reported figure.

⁴Hydrate.

⁵Data presented are for alumina for metallurgical use. Gross weight of aluminum hydrate for all uses was as follows, in thousand metric tons: 1987—711; 1988—778; 1989—863; 1990—890; and 1991—864.

⁶Data may not add to totals shown because of independent rounding.

ANTIMONY

By Thomas O. Llewellyn

Mr. Llewellyn, a physical scientist with more than 30 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for antimony since 1987. Domestic survey data were prepared by Elsie Isaac, statistical assistant; and international data were prepared by Ronald Hatch, international data assistant, Section of International Data.

The production and reported consumption of primary antimony products decreased in 1991 compared with that of 1990 as a result of a general softening of demand in the antimony market. Exports and imports of antimony products were also down from those of the previous year. A coalition of five U.S. antimony trioxide producers and/or manufacturers of antimony trioxide-based products filed an antidumping petition with the U.S. International Trade Commission (ITC) and the U.S. Department of Commerce, charging China with unfair trade practices.

DOMESTIC DATA COVERAGE

Domestic production data for antimony are developed by the U.S. Bureau of Mines from two voluntary surveys of U.S. operations. Typical of these surveys is the "Primary Antimony" survey. Of the six operations to which a survey request was sent, all responded, representing 100% of the primary smelter production shown in table 1 and 100% of the total antimony content of primary antimony production by class shown in table 2. (See table 1.)

BACKGROUND

Antimony, from the Greek *anti plus monos*, means "a metal seldom found alone." Although the name was intended to describe the metal's mineralogical association in ores, it also properly describes the use of antimony in modern industry because the metal is usually used

as an alloy with other metals. The natural sulfide of antimony, stibnite, was known and used in Biblical times as medicine and as a cosmetic for eyebrow painting. A vase found at Tello, Chaldea, reportedly cast in metallic antimony, indicates that in about 4000 B.C. the Chaldeans knew the art of reducing the sulfide to metal.

The known domestic deposits of antimony ore have generally been small and uneconomical when compared to foreign producers, resulting in a dependence on foreign sources of supply by the United States. Bolivia, China, Mexico, and the Republic of South Africa have historically been the principal sources of supply.

Definitions, Grades, and Specifications

Antimony is seldom found in nature as native metal because of its strong affinity for sulfur and the metallic elements such as copper, lead, and silver. Antimony in its elemental form is a silvery white, brittle, crystalline solid that exhibits poor electrical and heat conductivity properties. The National Stockpile Purchase Specification P-2a-R4, June 10, 1980, covered two grades of refined antimony metal ingot form. Grade A has a minimum antimony content of 99.8% and the following impurity maximums: arsenic, 0.05%; sulfur, 0.10%; lead, 0.15%; and other elements (copper, iron, nickel, silver, and tin), 0.05% each. Grade B material is composed of 99.5% antimony as a minimum with maximum impurity levels of 0.1% arsenic, 0.1%

sulfur, 0.2% lead, and 0.1% each of other elements.

Chemical-grade ore is that which is sufficiently pure to be used directly in producing the trioxide, chloride, or other industrial chemical compound. For chemical-grade sulfide ore, total impurities, including arsenic and lead, must not exceed 0.25%, and no single metallic impurity can exceed 0.1%.

Antimony trioxide, the most important of the antimony compounds, is used in flame-retarding formulations for many materials. Most commercial grades of antimony trioxide contain between 99.2% and 99.5% antimony trioxide with varying amounts of impurities such as arsenic, iron, and lead. Commercial suppliers offer various grades of antimony trioxide based on the relative tinting strength of their product, which is related to average particle size. In general, the tinting strength increases as the particle size decreases.

Industry Structure

Antimony was produced from ores and as a byproduct of the smelting of base metals ores in about 23 countries. China, the world's leading producer, accounted for about 54% of the total world estimated mine production during 1991. China together with the other four major producing countries, Bolivia, Mexico, the Republic of South Africa, and the U.S.S.R., accounted for about 90% of the total world antimony production. In 1991, antimony production from domestic source materials was largely derived from

recycling of lead-antimony batteries. Recycling plus mine output supplied less than one-half of the estimated domestic demand. Primary antimony was recovered as a byproduct from the smelting of domestic lead and from silver-copper ores.

Antimony metal and trioxide producers in the United States are essentially large, integrated companies with a variety of activities in marketing and manufacturing of base metals and chemical compounds. A few producers and processors of antimony have interests in foreign operations. Most purchase raw materials from mine and smelter operations either directly or through dealers.

Geology-Resources

Estimates of the abundance of antimony in the Earth's crust range from 0.2 to 0.5 parts per million. Antimony is chalcophile, occurring with sulfur and the heavy metals, copper, lead, and silver. More than 100 minerals of antimony are found in nature. Stibnite (Sb_2S_3) is the predominant ore mineral of antimony.

Simple antimony deposits consist principally of stibnite or, rarely, native antimony in a siliceous gangue, commonly with some pyrite, and in places a little gold and small amounts of other metal sulfides, principally silver and mercury. Antimony ores commonly are associated with igneous activity and have common genetic association with such intrusives as granite, diorites, and monzonites. The mineralogy of the veins and their almost invariably shallow depth suggest a low temperature of formation at near-surface positions, possibly related to the configuration of the water table at the time of deposition. Most of these geologically simple stibnite deposits do not individually contain more than several thousand tons of ore. Deposits of this type are found in the world's most productive antimony districts, including those of Bolivia, China, Mexico, and the Republic of South Africa.

Complex antimony deposits consist of stibnite associated with pyrite, arsenopyrite, cinnabar, or scheelite, or of antimony sulfosalts with varying amounts

of copper, lead, and silver, as well as common sulfides of these metals and zinc. Ores of the complex deposits generally are mined primarily for gold, lead, silver, tungsten, or zinc.

Most of the antimony produced in the United States is from complex deposits. The tetrahedrite ores found in the Coeur d'Alene district of Idaho are outstanding examples of complex deposits.¹

Principal identified world antimony resources, at about 5 million tons, are in Bolivia, China, Mexico, the Republic of South Africa, and the U.S.S.R. U.S. resources are mainly in Alaska, Idaho, Montana, and Nevada.

Technology

Antimony deposits are seldom explored in advance of actual mining because the deposits are generally small, irregular, and difficult to appraise.

Many of the typically small mines contain irregular and scattered ore bodies that cannot be readily exploited by large-scale mining methods. Mining methods used in mines that recover metalliferous ores, of which antimony is a minor constituent, are designed for producing the principal metals such as gold, lead, or silver.

The antimony content of ores determines the method of recovery. In general, the lowest grades of sulfide ores, 5% to 25% antimony, are roasted; 25% to 40% antimony ores are smelted in a blast furnace; and 45% to 60% antimony ores are liquated. At some mines in Bolivia and the Republic of South Africa, the high-grade sulfide ore is concentrated by hand-cobbing and sold as lump sulfide ore, 60% antimony content. As higher grade deposits have become depleted, increasing emphasis has been placed on upgrading low-grade ores by flotation.

Roasting of the ore to yield a volatile trioxide or the stable nonvolatile tetroxide is the only pyrometallurgical procedure suitable for low-grade ores (5% to 25% antimony content). The sulfur is oxidized and removed from waste gases, and the volatilized antimony oxide is recovered in flues, condensing pipes, a baghouse, precipitators, or a combination of the

above. The temperature and quantity of available oxygen determine the kind and quantity of the oxide produced. The oxide produced by this method is generally impure and can be reduced to metal. However, careful control of volatilization conditions will produce a high-grade oxide that can be sold directly to consumers.

Water-jacketed blast furnaces are used in several plants to reduce ores containing 25% to 40% antimony. Oxides, sulfides, or mixed ores, residues, mattes, slags, and briquetted fines or flue dusts can be used as blast furnace charges. A high smelting column and comparatively low air pressure are used, and the slag and metal are separated in the hearth.

Antimony sulfide can be separated from the gangue of sulfide ores by melting in a reverberatory furnace. A reducing atmosphere is kept to prevent oxidation. The solidified product is called liquated or needle antimony and may be used as sulfide or converted to antimony metal by iron precipitation.

Some complex ores can be treated by leaching and electrowinning to recover the antimony. A typical process uses an alkali hydroxide or sulfide as the solvent. The filtered leach solution containing sodium thioantimonate, Na_3SbS_4 , is electrolyzed in a diaphragm cell using an iron or lead anode and an iron or mild-steel cathode. The cathode metal obtained is 93% to 99% pure antimony.² Antimony metal is also produced as antimonial lead, which is an important product of the secondary lead smelter. A blast furnace charge containing used or discarded battery plates, type metal, and bearing metal is reduced to a lead bullion. The bullion is refined in reverberatory furnaces and melting pots to meet specifications.

Byproducts and Coproducts

Most of the domestic primary antimony production is a byproduct or coproduct of mining, smelting, and refining other metals and ores that contain relatively small quantities of antimony. In 1991, domestic production of antimony was mainly a byproduct of treatment of

tetrahedrite, a complex silver-copper-antimony sulfide ore. An undisclosed amount of antimony was also recovered as a byproduct of the processing of lead ores.

The antimony deposits of the Republic of South Africa contain gold. High-grade Bolivian antimony ores contain variable and minor values of gold and tungsten and objectionable amounts of arsenic, copper, and lead in some deposits. Chinese ores contain some tungsten.

Substitutes

Compounds of chromium, tin, titanium, zinc, and zirconium substitute for antimony chemicals in paint, pigments, frits, and enamels. A combination of cadmium, calcium, copper, selenium, strontium, sulfur, and tin can be used as substitutes for hardening lead. Selected organic compounds and hydrated aluminum oxide are widely accepted alternative materials in flame-retardant systems.

Economic Factors

Antimony and antimony trioxide are taxed under the new Superfund Amendments and Reauthorization Act of 1986, Public Law 99-499. The taxes, to be collected from producers and importers, were \$4.90 per ton of antimony metal and \$4.13 per ton of antimony trioxide. The taxes have been rescheduled to end on December 31, 1995.

Antimony producers are granted a depletion allowance of 22% on domestic production and 14% on foreign production.

Under the new Harmonized Tariff Schedule of the United States, which took effect January 1, 1989, antimony ore and concentrates imports from most favored nations (MFN) and non-most-favored nations (non-MFN) were duty free. Antimony and articles thereof, including waste and scrap, and antimony oxide were duty free for MFN. However, from non-MFN a statutory duty of 4.4 cents per kilogram was imposed.

Operating Factors

Environmental and ecological problems associated with the processing of antimony metal and ores are minimal because emissions and effluents are controlled at the processing site.

The major conservation practice of the antimony industry is the recycling of the metal in used storage batteries, type metal, and babbitt. Antimony metal and antimonial lead from intermediate smelter products such as slags, drosses, flue dusts, and residues generated at copper and lead smelters are recovered at lead smelters.

Energy requirements for the production of antimony metal and antimony trioxide from stibnite ores are 163 million British thermal units (Btu's) per net ton of antimony metal and 186 million Btu's per net ton of antimony trioxide.³

An estimated 210 persons are employed in the domestic production of antimony ores and in conversion of antimony ores and raw materials to antimony metal and compounds.

ANNUAL REVIEW

Legislation and Government Programs

On April 25, 1991, a coalition of five U.S. antimony trioxide producers and/or manufacturers of antimony trioxide-based products filed an antidumping petition with the United States ITC and the U.S. Department of Commerce, charging China with unfair trade practices.

The coalition members requesting the initiation of an investigation, on behalf of the U.S. refining antimony trioxide industry, were: Anzon Inc. and Atochem North America, Inc. of Philadelphia, PA; Laurel Industries Inc. of Cleveland, OH; U.S. Antimony Corp. of Thompson Falls, MT; and U.S. Antimony Sales Corp. of Natick, MA.⁴

On June 5, 1991, the ITC's preliminary investigation determined that there was a reasonable indication of material injury or threatened material injury to the domestic antimony trioxide refining industry as a result of

Chinese-refined antimony trioxide imports.⁵

On October 9, 1991, the Commerce Department announced its preliminary determination that all Chinese antimony trioxide entering the United States should be assessed a dumping margin of 3.18%.⁶

On October 23, 1991, the ITC established a schedule for its final antidumping duty investigation of refined antimony trioxide imported from China. At the request of Chinese officials on November 6, 1991, the Department of Commerce extended the date for its final determination in the investigation from December 16, 1991, to February 21, 1992. To conform with the new schedule by the Department of Commerce, the ITC also revised its schedule for the final investigation, and the hearing scheduled for December 19, 1991, was rescheduled to be held on February 25, 1992, at the ITC building, 500 E Street, SW, Washington, DC.⁷

Strategic Considerations

Antimony was included in the National Defense Stockpile because of its strategic uses in flame-retardant compounds, friction bearings, and batteries.

No inventory acquisitions or sales were made during the year, and, as of December 31, 1991, the stockpile inventory was 32,658 metric tons of antimony metal.

Domestic Production

Mine Production.—Sunshine Mining Co. produced antimony as a byproduct of the treatment of tetrahedrite, a complex silver-copper-antimony sulfide ore, from the Coeur d'Alene district of Idaho.

Smelter Production.—Primary.—The producers of primary antimony metal and oxide products were ASARCO Incorporated, Omaha, NE; Amspec Chemical Corp., Gloucester City, NJ; Anzon Inc., Laredo, TX; Laurel Industries Inc., La Porte, TX; Sunshine Mining Co., Kellogg, ID; and U.S.

Antimony Corp., Thompson Falls, MT. (See table 2.)

Secondary.—Old scrap, predominantly lead battery plates, was the source of most of the secondary antimony output. New scrap, mostly in the form of drosses and residues from various sources, supplied the remainder. The antimony content of scrap was usually recovered and consumed as antimonial lead. (See table 3.)

Consumption and Uses

Reported domestic consumption of primary antimony products decreased in 1991 compared with 1990 as a result of a general softening of demand in the antimony market. Lead-antimony alloys were used in starting-lighting-ignition batteries, ammunition, corrosion resistant pumps and pipes, tank linings, roofing sheets, solder, cable sheaths, and antifriction bearings.

Antimony compounds were used in plastics both as stabilizers and as flame retardant. Antimony trioxide in an organic solvent was used to make textiles, plastics, and other combustibles flame retardant. Antimony was used as a decolorizing and refining agent in some forms of glass, such as special optical glass. The estimated distribution of antimony uses was flame retardants, 73%; transportation, including batteries, 9%; chemicals, 9%; ceramics and glass, 4%; and other, 5%. (See tables 4, 5, and 6.)

Markets and Prices

The New York dealer antimony metal price, published by Metals Week, started the year ranging from \$0.78 to \$0.80 per pound, held steady during January, and increased to a range of \$0.84 to \$0.85 per pound by mid-March. At yearend, the dealer price range was listed at \$0.82 to \$0.84 per pound.

The price range for high-tint antimony trioxide was \$1.10 per pound at the beginning of the year and remained constant for the rest of 1991.

The European price range quotation for clean antimony sulfide concentrate (60% antimony content), published by Metal Bulletin (London), which was \$15 to \$17 per metric ton unit at the beginning of 1991, decreased to a range of \$14.50 to \$16.50 per metric ton unit at the beginning of the second quarter, and remained constant for the rest of the year. The European price range quotation for lump antimony sulfide ore (60% antimony content) held steady at \$15.50 to \$17 per metric ton unit during 1991. (See tables 7, 8, 9, 10, and 11.)

World Review

Capacity.—The data in table 12 represent rated annual production capacity for mines and refineries on December 31, 1991. Rated capacity was defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable, long-term operating rate, based on the physical equipment of the plant and routine operating procedures for labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

The rated capacity of mines and refineries for antimony was estimated based on discussions with some officials from private industry, past and present production rate, and published capacity data. (See tables 12 and 13.)

Bolivia.—Once more antimony producers from Bolivia and China attempted to control the prices of antimony through a bilateral agreement. Both countries agreed to set a quarterly minimum reference price of \$1,760 per metric ton for metal and \$15.20 per metric ton unit of concentrate (60% antimony content), c.i.f. Rotterdam. This new antimony agreement was signed on May 15, 1991. The previous agreement signed between these two countries was on January 7, 1989; but in May 1990, Bolivian officials withdrew their

participation in the joint Bolivian-Chinese effort to control producer prices as, in their opinion, the agreement failed to achieve its objective of coordinating policies of the two countries on antimony production and trade.⁸ The new antimony agreement was seen by American and European traders as another possible failure.

Japan.—Antimony trioxide production, mainly from imported materials, was 11,908 tons, an increase of about 8% compared with 1990 production. Antimony metal production also increased from 216 tons in 1990 to 262 tons in 1991.

Current Research

Antimony content in the aluminum scrap supply could become an increasing problem as more Japanese and European cars, as well as other consumed materials, enter the waste-recycling stream. Japan and Europe use antimony to modify the physical properties of aluminum alloys while the United States usually does not. Aluminum-bearing antimony should not be used to manufacture cooking utensils. Stibine (SbH_3), a gaseous poisonous binary compound of antimony with hydrogen, could form when a cooking utensil is exposed to an acidic environment. Researchers at the Argonne National Laboratory in Argonne, IL, have successfully removed about 99.9% of the antimony content from a molten aluminum-antimony alloy by adding calcium metal to the melt. It is believed that the calcium and antimony combined to form an insoluble intermetallic compound that reports to the aluminum oxide surface slag.⁹

OUTLOOK

Mining, beneficiation, and metallurgical procedures for antimony have changed little in the past 30 years. No new technological developments that would affect productivity are foreseen for the future.

The oversupply of antimony products from China that has saturated the market in the past 3 years will continue during 1992, and unless China's policy of offering discounts from the world market price shows signs of changing, the prospects for Western antimony trioxide producers will remain not very good.

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²Carapella, Jr., S. C. Antimony and Antimony Alloys. Ch. in Encyclopedia of Chem. Technol. Kirk-Othmer, 3d ed., v. 22, 1983, pp. 96-105.

³Battelle Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 6-Energy Data and Flowsheet, Low-Priority Commodities) (contract 01444093). BuMines OFR 117(1)-76, 1976, pp. 8-14; NTIS PB 261150/AS.

⁴Federal Register. United States International Trade Commission. Refined Antimony Trioxide From the People's Republic of China. V. 56, No. 86, May 3, 1991, pp. 20443-20444.

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⁶Federal Register. Department of Commerce--Import Administration, International Trade Administration. Preliminary Determination of Sales at Less Than Fair Value: Refined Antimony Trioxide From the People's Republic of China. V. 56, No. 196, Oct. 9, 1991, pp. 50849-50852.

⁷United States International Trade Commission. Refined Antimony Trioxide From the People's Republic of China. Action: Revised Schedule for the Subject Investigation. V. 56, No. 233, Dec. 4, 1991, pp. 63524-63525.

⁸Metal Bulletin. China and Bolivia in New Antimony Accord. No. 7574, May 27, 1991, p. 27.

⁹Kuster, T. Argonne Tests Method for Removing Antimony. American Metal Market, v. 99, No. 52, Mar. 19, 1991, p. 4.

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TABLE 1
SALIENT ANTIMONY STATISTICS

(Metric tons of antimony content unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Production:					
Primary:					
Mine (recoverable antimony)	—	W	W	W	W
Smelter	17,930	17,616	18,954	*20,070	16,032
Secondary	15,833	16,172	19,501	*20,351	20,898
Exports of metal, alloys, waste and scrap	795	624	293	588	694
Exports of antimony oxide	705	1,227	1,850	*7,142	3,752
Imports for consumption	24,248	30,027	25,165	29,403	28,833
Reported industrial consumption, primary antimony	10,373	12,067	13,424	*12,766	11,902
Stocks: Primary antimony, all classes, Dec. 31	6,093	6,498	6,270	*8,175	10,166
Price: Average, cents per pound ¹	110.6	103.9	94.3	81.8	82.0
World: Mine production	69,955	*70,607	*65,297	*66,846	*64,730

¹Estimated. ²Revised. W Withheld to avoid disclosing company proprietary data.
³New York dealer price for 99.5% to 99.6% metal, c.i.f. U.S. ports.

TABLE 2
PRIMARY ANTIMONY PRODUCED OR GENERATED IN THE UNITED STATES

(Metric tons of antimony content)

Year	Class of material produced or generated			Total
	Metal	Oxide	Residues	
1987	W	17,892	38	17,930
1988	W	17,150	466	17,616
1989	W	18,720	234	18,954
1990	W	*19,438	632	*20,070
1991	W	16,032	W	16,032

¹Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

TABLE 3
SECONDARY ANTIMONY PRODUCED IN THE UNITED STATES, BY
KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons of antimony content unless otherwise specified)

	1990	1991
KIND OF SCRAP		
New scrap: Lead- and tin-base	*1,164	1,306
Old scrap: Lead- and tin-base	*19,187	19,592
Total	*20,351	20,898
FORM OF RECOVERY		
In antimonial lead	*19,756	20,323
In other lead- and tin-base alloys	*595	575
Total	*20,351	20,898
Value (millions)	\$42	\$43

*Revised.

TABLE 4
REPORTED INDUSTRIAL CONSUMPTION OF PRIMARY ANTIMONY IN
THE UNITED STATES

(Metric tons of antimony content)

Year	Class of material consumed				Total
	Metal	Oxide	Sulfide	Residues	
1987	2,248	8,048	39	38	10,373
1988	2,121	9,438	42	466	12,067
1989	2,523	10,640	27	234	13,424
1990	*2,144	*9,965	25	632	*12,766
1991	2,537	9,339	26	W	11,902

*Revised. W Withheld to avoid disclosing company proprietary data, not included in "Total."

TABLE 5
REPORTED INDUSTRIAL CONSUMPTION OF PRIMARY ANTIMONY IN THE UNITED STATES, BY PRODUCT

(Metric tons of antimony content)

Product	1987	1988	1989	1990	1991
Metal products:					
Ammunition	W	W	521	602	W
Antimonial lead	1,102	1,538	1,871	2,010	1,705
Bearing metal and bearings	187	178	129	90	76
Cable covering	W	W	W	W	W
Castings	8	13	8	8	8
Collapsible tubes and foil	W	—	—	—	—
Sheet and pipe	76	181	157	123	W
Solder	347	256	245	208	223
Type metal	8	6	4	3	W
Other	584	609	80	106	916
Total	<u>2,312</u>	<u>2,781</u>	<u>3,015</u>	<u>3,150</u>	<u>2,928</u>
Nonmetal products:					
Ammunition primers	32	34	20	23	23
Ceramics and glass	1,122	1,221	1,050	991	870
Fireworks	2	4	5	3	2
Pigments	279	179	196	246	207
Plastics	750	916	1,141	1,148	1,127
Rubber products	W	29	97	27	W
Other	199	147	159	151	60
Total	<u>2,384</u>	<u>2,530</u>	<u>2,668</u>	<u>2,589</u>	<u>2,289</u>
Flame-retardants:					
Adhesives	315	251	219	189	264
Paper	W	W	W	W	W
Pigments	30	104	926	502	W
Plastics	4,139	5,469	5,851	5,678	5,000
Rubber	387	282	166	181	227
Textiles	800	643	558	460	513
Other	6	7	21	17	681
Total	<u>5,677</u>	<u>6,756</u>	<u>7,741</u>	<u>7,027</u>	<u>6,685</u>
Grand total	<u>10,373</u>	<u>12,067</u>	<u>13,424</u>	<u>12,766</u>	<u>11,902</u>

Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."

TABLE 6
INDUSTRY STOCKS OF PRIMARY ANTIMONY
IN THE UNITED STATES, DECEMBER 31

(Metric tons of antimony content)

Stocks	1987	1988	1989	1990	1991
Metal	822	2,360	1,873	2,934	3,598
Ore and concentrate	1,148	W	W	W	(¹)
Oxide	4,018	3,840	4,079	4,380	3,334
Residues	83	274	302	844	(¹)
Sulfide	22	24	16	17	(¹)
Total	6,093	6,498	6,270	8,175	10,166

¹Revised. W Withheld to avoid disclosing company proprietary data; not included in Total.

²Data withheld to avoid disclosing company proprietary data; included in "Total."

TABLE 7
ANTIMONY PRICE RANGES
IN 1991, BY TYPE

Type	Price per pound
Domestic metal ¹	\$1.25-\$1.40
Foreign metal ²	.80 -.82
Antimony trioxide ³	1.10 -1.20

¹Based on antimony in alloy.

²Duty-paid delivery, New York.

³Producer price, published by ASARCO Incorporated, for high-tint antimony trioxide.

TABLE 8
U.S. EXPORTS OF ANTIMONY METAL, ALLOYS,
WASTE AND SCRAP, BY COUNTRY

Country	1990		1991	
	Gross weight (metric tons)	Value (thousands)	Gross weight (metric tons)	Value (thousands)
Belgium	299	\$345	594	\$815
Canada	66	188	45	130
Guatemala	5	30	5	27
Mexico	23	74	12	42
United Kingdom	133	269	2	29
Venezuela	40	121	34	68
Other	22	116	(¹)	27
Total	588	1,143	2,694	1,138

¹Revised.

²Less than 1/2 unit.

³Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 9
U.S. EXPORTS OF ANTIMONY OXIDE, BY COUNTRY

Country	1990			1991		
	Gross weight (metric tons)	Antimony content ¹ (metric tons)	Value (thousands)	Gross weight (metric tons)	Antimony content ¹ (metric tons)	Value (thousands)
Belgium	5	4	\$21	28	23	\$127
Brazil	15	12	71	12	10	39
Canada	768	637	2,324	450	374	1,336
Colombia	35	29	111	56	46	182
Egypt	10	8	11	10	8	24
France	21	17	60	3	2	8
Germany, Federal Republic of	58	48	257	121	100	409
India	7	6	34	8	7	26
Indonesia	4	3	13	5	4	17
Israel	36	30	98	17	14	47
Italy	1,063	882	1,676	71	59	105
Japan	220	183	598	222	184	625
Korea, Republic of	21	17	65	24	20	75
Mexico	5,791	4,807	6,954	2,707	2,247	2,814
Netherlands	179	149	843	15	12	56
Singapore	186	154	303	279	232	422
Spain	51	42	131	53	44	127
Sweden	5	4	5	5	4	5
Taiwan	34	28	136	83	69	269
Turkey	6	5	26	48	40	158
United Kingdom	17	14	65	40	33	49
Venezuela	15	12	50	11	9	41
Other	58	51	110	253	211	443
Total	8,605	7,142	13,962	4,521	3,752	7,404

¹Revised.

¹Estimated by the U.S. Bureau of Mines.

Source: Bureau of the Census.

TABLE 10
U.S. IMPORTS FOR CONSUMPTION OF ANTIMONY, BY CLASS AND COUNTRY

Country	1990			1991		
	Gross weight (metric tons)	Antimony content ¹ (metric tons)	Value (thousands)	Gross weight (metric tons)	Antimony content ¹ (metric tons)	Value (thousands)
Antimony ore and concentrate:						
Bolivia	1,045	608	\$869	197	134	\$149
Canada	47	42	41	81	40	33
Chile	66	48	98	165	164	231
China	2,759	1,844	2,610	2,742	2,294	3,515
Guatemala	480	269	141	29	4	16
Hong Kong	192	121	233	172	163	236
Mexico	914	361	604	428	209	258
Other	178	160	238	581	374	811
Total²	5,681	3,454	4,835	4,395	3,381	5,250
Antimony oxide:						
Belgium	573	476	1,654	763	633	2,283
Bolivia	658	546	1,152	1,633	1,355	2,685
China	5,049	4,191	7,837	5,277	4,380	7,249
France	494	410	1,245	248	206	550
Germany, Federal Republic of	90	74	909	92	77	954
Hong Kong	511	424	801	164	136	272
Mexico	4,179	3,469	4,224	3,871	3,213	3,551
Netherlands	53	44	183	55	46	187
South Africa, Republic of	2,657	2,205	913	2,176	1,806	740
United Kingdom	62	51	354	93	77	370
Other	144	119	301	26	21	100
Total²	14,472	12,012	19,574	14,397	11,950	18,941

²Revised.

¹Antimony ore and concentrate content reported by Bureau of the Census. Antimony oxide content estimated by the U.S. Bureau of Mines.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 11
U.S. IMPORTS FOR CONSUMPTION OF ANTIMONY METAL, BY
COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Bolivia	130	\$191	183	\$274
Chile	74	110	89	124
China	11,862	19,584	11,900	18,831
Hong Kong	162	253	558	831
Japan	91	640	84	2,532
Mexico	185	163	400	121
Taiwan	112	309	14	123
Thailand	1,054	1,580	220	353
Other	271	550	53	652
Total¹	13,940	23,380	13,502	23,841

¹Revised.

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 12
WORLD ANNUAL ANTIMONY
PRODUCTION CAPACITY,
DECEMBER 31, 1991

(Metric tons, antimony content)

	Mine	Smelter ¹
North and Central America:		
United States	3,000	30,000
Other	8,000	4,000
Total	11,000	34,000
South America	15,000	8,000
Europe	16,000	28,000
Africa	13,000	5,000
Asia ²	45,000	35,000
Oceania: Australia	2,000	—
Total	102,000	110,000

¹Includes antimony oxide plants.

²Includes estimates for China.

TABLE 13
ANTIMONY: WORLD MINE PRODUCTION, BY COUNTRY¹

(Metric tons)

Country	1987	1988	1989	1990	1991 ^a
Australia ²	1,231	1,320	1,360	¹ 1,420	1,500
Austria	322	228	350	² 352	—
Bolivia	10,635	9,943	8,533	³ 8,454	³ 7,532
Canada ⁴	3,706	3,171	2,818	653	600
China ^a	27,000	30,000	30,000	¹ 35,000	35,000
Czechoslovakia ^a	1,000	² 2,921	600	¹ 1,270	1,000
Guatemala	1,881	921	1,343	¹ 1,050	1,000
Honduras	28	19	³ 30	¹ (⁵)	—
Italy	86	⁶ 60	—	—	—
Malaysia (Sarawak)	129	—	—	—	³ —
Mexico ⁶	2,839	2,185	1,906	² 2,614	³ 2,900
Morocco (content of concentrate)	444	250	142	¹ 192	190
Namibia (content of sodium antimonate)	24	73	34	⁴ 47	50
Pakistan	7	—	8	⁷ 9	8
Peru (recoverable)	590	420	519	⁵ 560	600
South Africa, Republic of (content of concentrate)	6,673	⁶ 6,264	⁵ 5,201	⁴ 4,815	4,500
Spain ^a	20	20	¹ (⁶)	—	—
Thailand	409	445	495	⁵ 500	500
Turkey	2,344	1,877	¹ 1,350	¹ 400	400
U.S.S.R. ^a	9,600	9,600	9,600	9,000	8,500
United States	—	W	W	W	W
Yugoslavia	834	725	798	⁴ 409	350
Zimbabwe (content of concentrate)	153	165	210	¹ 101	100
Total	69,955	⁷ 70,607	⁶ 65,297	⁶ 66,846	64,730

^aEstimated. ¹Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

¹Antimony content of ore unless otherwise indicated. Table includes data available through May 20, 1992.

²Antimony content of antimony ore and concentrate, lead concentrates, and lead-zinc concentrates.

³Reported figure.

⁴Partly estimated on basis of reported value of total production.

⁵Revised to zero.

⁶Antimony content of ores for export plus antimony content of antimonial lead and other smelter products produced.

ARSENIC

By J. Roger Loebenstein

Mr. Loebenstein, a physical scientist with 17 years industry and U.S. Bureau of Mines experience, has been the commodity specialist for arsenic since 1987. Domestic survey data were prepared by Evangeline Hemphill, mineral data assistant; and international data tables were prepared by Harold Willis, international data coordinator.

Aside from small amounts of arsenic trioxide shipped from remaining stocks at ASARCO Incorporated's closed plant at Tacoma, WA, the United States imported all of the arsenic it required in 1991. More than 93% of the arsenic was imported as the trioxide, another 2% as arsenic acid and arsenic sulfide, and less than 5% as metal.

A major producer of arsenic trioxide in Sweden, Boliden Mineral AB, permanently shut down production, reportedly because of environmental problems. At about the same time, China emerged as the world's largest producer of both arsenic trioxide and arsenic metal, selling large amounts of both commodities to the United States.

ANNUAL REVIEW

Legislation and Government Programs

In 1991, the Environmental Protection Agency (EPA) announced its preliminary decision to cancel the registration of products containing arsenic acid used as a desiccant on cotton. The Agency provided for a period of hearings before making its final decision.¹ EPA estimated that current usage of arsenic acid is 2 to 3 million pounds per year, representing 5% to 10% of total U.S. cotton acreage.² It suggested that another chemical, paraquat, possibly could be used as a substitute for arsenic acid. A final ruling by EPA on the use of arsenic acid as a desiccant on cotton was not expected until sometime in 1992.

California's Department of Health Services received a recommendation to lower its drinking water standard for arsenic severely, from 50 parts per

billion, the current Federal standard, to 2 parts per billion. A new risk assessment by the State's Environmental Protection Agency indicated that lifetime consumption of drinking water with levels of arsenic at 50 parts per billion presents a 1% risk of cancer.³

In California, hazardous water has been found primarily in 200 deep wells in Kings, Kern, San Joaquin, and Sonoma Counties. The arsenic is believed to enter water supplies from underground deposits in highly porous rock where wells are often drilled—particularly in desert areas and near mountains.

Issues

In January 1992, a Panamanian ship traveling from New York to Baltimore via Delaware Bay encountered a storm off the coast of Cape May, NJ, and lost four containers of arsenic trioxide weighing a total of 75 metric tons. Subsequently, the Justice Department filed suit against the owner of the Panamanian freighter to help pay for the cleanup. About \$2.7 million in Superfund cleanup money was approved by EPA to help cover the costs of the extensive search and recovery of the arsenic-containing drums. Total cost of recovery was estimated at about \$5 million. The Commerce Department prohibited fishing in the vicinity of the spill.

The U.S. Coast Guard reportedly recovered three of the four shipping containers that were lost at sea, but the fourth container was never located. Of the 440 drums of arsenic trioxide that were lost, 329 were recovered, but not all of the recovered drums were found with

their contents intact.

The U.S. Bureau of Mines began a study of the flow of arsenic-containing materials in the United States. Aspects of materials flow considered in this study include arsenic generated as a result of processing other metals, manufacturing wastes, dissipative uses, and disposal of products.

Consumption

Arsenic trioxide was converted to arsenic acid for use in the production of arsenical wood preservatives by three principal companies, Hickson Corp., Chemical Specialities, Inc., and Osmose Corp. Chromated copper arsenate (CCA) is the most common arsenic-base wood preservative. Other arsenic-base wood preservatives include ammoniacal copper arsenate (ACA) and fluor chrome arsenate phenol (FCAP).

The only two remaining major agricultural uses for arsenic are as herbicides (monosodium methanearsonate or MSMA and disodium methanearsonate or DSMA) for control of weeds and arsenic acid to aid in the mechanical harvesting of cotton in Oklahoma and Texas. ISK Biotech (formerly Fermenta Corp.), Mentor, OH, produced the arsenical herbicide MSMA at a plant in Houston, TX. Atochem Corp., Bryan, TX, was a major producer of arsenic acid for use by cotton growers and wood preservative companies.

Minor amounts of arsenic acid were used by glass companies such as Corning Glass, Corning, NY. Arsenic acid is used as a fining agent to disperse bubbles that tend to form when certain types of glass are produced. As a result of EPA

regulations that became effective in 1986, arsenic emissions from glass furnaces have been sharply reduced.

Commercial-grade arsenic metal, 99% pure, was used in lead- and copper-base alloys as a minor additive (about 0.01% to 0.5%) to increase strength in the posts and grids of lead-acid storage batteries and to improve the corrosion resistance and tensile strength in copper alloys.

Relatively small quantities of high-purity arsenic metal, of 99.99% or higher purity, were used in the manufacture of crystalline gallium arsenide, a semiconducting material used in optoelectronic circuitry, high-speed computers, and other devices. Convex Computer Corp., Richardson, TX, shipped seven of its C3800 model computers in 1991. According to the company, this is the first supercomputer to be fully implemented with gallium arsenide semiconductor technology.

Prices

Prices for arsenic trioxide, 99% pure from Mexico, and arsenic metal, 99% pure from Mexico, are shown in table 2. The average price for Mexican arsenic trioxide increased slightly in 1991 to \$0.25 per pound, while the price of arsenic metal imported from China was down substantially to \$0.68 per pound, a decline from a record-high level in 1990. In 1990, a disruption in supply of arsenic metal from China caused prices to temporarily skyrocket.

Prices for arsenic trioxide are not readily available from published sources, although historical prices from 1955 to 1990 are published in the Chemical Economics Handbook published by SRI International, Menlo Park, CA. Normally, producers quote two prices, one for high-grade (minimum 99%) arsenic trioxide and one for low-grade (minimum 95%) arsenic trioxide. There is a spread of \$0.08 to \$0.12 per pound between the prices of the two grades. The U.S. Bureau of Mines has published yearend arsenic metal prices from 1921 through 1988.⁴

Foreign Trade

The United States imported more than 7,000 metric tons of arsenic trioxide from China in 1991, a large increase from no imports at all in 1989, as shown in table 3. China was also the largest supplier of arsenic metal to the United States in 1991.

Chile was the second largest source of arsenic trioxide imports in 1991, providing slightly less than one-quarter of total U.S. imports. Cia. Minera San José Ltd. produced arsenic trioxide as a byproduct of gold-copper ores roasted at its El Indio smelter. The company was expected to increase production when a new roaster is added to its smelter, sometime in 1992.

World Review

Arsenic was recovered as arsenic trioxide from the smelting or roasting of nonferrous metal ores or concentrates in about 16 countries, as shown in table 4. Annual arsenic trioxide refinery production capacities for the three leading countries were as follows: China, 12,000 tons; Chile, 10,000 tons; and the U.S.S.R., 10,000 tons. Of the producing countries, only Chile and China have countered the trend in recent years toward decreasing arsenic production.

Several changes occurred in producing countries in 1991. Historically, Sweden has been an important producer, but production was shut down permanently in 1991, reportedly for environmental reasons. In France, one of the two major producers of arsenic trioxide from gold ores, Mine et Produits Chimiques de Salsigne, declared bankruptcy. The producers in Belgium and Mexico were under increased pressure to reduce production by Governments concerned with environmental problems associated with arsenic and its potential release to the environment.

Consumers reported that the Chinese arsenic trioxide was generally poor in quality, 97% to 98% pure, and contained a high degree of moisture and foreign material, such as rocks and pebbles. China is believed to be the only country

in the world that produces arsenic trioxide directly from arsenic ores.

Arsenic metal, which accounts for only 3% of world demand for arsenic, was produced by the reduction of arsenic trioxide. Commercial-grade arsenic metal, 99% pure, which accounted for the majority of arsenic metal production, was produced only in China. High-purity arsenic, 99.99% pure or greater, for use in the semiconductor industry was produced in about 10 companies. Furukawa Electric Co. Ltd. in Japan and Preussag AG in Germany were believed to be the world's largest producers, with reported capacities of 30 and 15 tons per year, respectively. Other high-purity arsenic producers included Mitsubishi Metal Corp. and Rasa Industries Ltd. in Japan and Johnson Matthey Ltd. and MCP Electronic Materials Ltd. in the United Kingdom. In Canada, Johnson Matthey Ltd. reportedly stopped production of high-purity arsenic metal early in 1992. The company is continuing to produce gallium arsenide wafers for use in the electronics industry.

OUTLOOK

The anticipated shortfall in arsenic trioxide supplies in 1991 due to Boliden's decision to shut down production in Sweden did not materialize because other producers, most notably Chile and China, made up for the shortfall.

The major market for arsenic is in wood preservatives. The future for arsenic consumption is therefore tied to new housing, where wood decks containing arsenical preservatives have become almost standard items in recent years. Treated wood is also used in decks added to existing houses. The growth of wood preservatives is expected to average 1% to 2% per year for the duration of the current economic recession. No major environmental problems associated with the use of arsenicals in wood preservatives is anticipated because of the small amounts of arsenic used and the fact that arsenic does not readily leach from treated wood.

The use of arsenic in agricultural chemicals has been under close scrutiny

by EPA for many years. Many pesticide uses for arsenical chemicals have been banned by EPA or voluntarily withdrawn by their manufacturers, while the use of the arsenic acid as a cotton desiccant could be banned as early as 1992 (see section under Legislation and Government Programs). The outlook for agricultural chemicals is expected to continue to be negative over the next 5 years.

Gallium arsenide components compete with silicon components in electronic applications. Gallium arsenide components are faster, but silicon components are cheaper. Advances in computer technology have led to the move from linear to parallel arrangement of processors, thus minimizing the relative slowness of silicon. For this reason, it is unlikely that gallium arsenide will replace silicon in most electronic applications, despite growth in gallium arsenide production capacity.

¹Federal Register. U.S. Environmental Protection Agency. Inorganic Arsenicals; Preliminary Determination To Cancel Registration of Pesticides Containing Inorganic Arsenicals Registered for Non-wood Preservative Use: Availability of Technical Support Document; Notice of Intent To Cancel. Oct. 7, 1991, pp. 50576-50585.

²U.S. Environmental Protection Agency. Office of Pesticides and Toxic Substances, Office of Pesticide Programs. Inorganic Arsenicals, Technical Support Document, Oct. 1991, 53 pp.

³Science News. Arsenic in Water: Bigger Cancer Threat. Apr. 18, 1992, p. 253.

⁴U.S. Bureau of Mines. Nonferrous Metal Prices in the United States Through 1988. Spec. publ., 135 pp.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Arsenic. Ch. in Mineral Commodity Summaries 1992.

Gallium in 1991. Mineral Industry Surveys, Annual Review.

Other Sources

Roskill Information Services Ltd., Arsenic 1990, 7th ed.

TABLE 1
ARSENIC SUPPLY-DEMAND RELATIONSHIPS, 1987-91

(Metric tons, arsenic content)

	1987	1988	1989	1990	1991
U.S. supply:					
Imports, metal	631	600	928	796	1,007
Imports, compounds	21,078	21,705	21,498	19,897	20,741
Industry stocks, Jan. 1 ¹	400	200	100	100	100
Total	22,109	21,505	22,526	20,793	21,848
Industry stocks, Dec. 31 ¹	200	100	100	100	—
Exports ²	50	120	126	149	233
Apparent demand	21,859	22,285	22,300	20,544	21,615
Estimated U.S. demand pattern:¹					
Agricultural chemicals	5,000	5,100	4,900	4,200	5,000
Glass	900	900	900	800	900
Industrial chemicals	15,100	15,400	15,600	14,400	14,300
Nonferrous alloys and electronics	400	500	700	800	1,000
Other	500	400	200	300	400
Total	21,900	22,300	22,300	20,500	21,600

¹Revised.

²Figures are rounded.

³Exports for 1987 and 1988 include compounds; exports for 1989 through 1991 include metal only.

TABLE 2
AVERAGE ARSENIC PRICE
QUOTATIONS

(Cents per pound)

	1989	1990	1991
Trioxide, Mexican	27	23	25
Metal, Chinese	47	180	68

Source: Calculated from Bureau of the Census import data.

TABLE 3
U.S. IMPORTS FOR CONSUMPTION OF ARSENICALS, BY CLASS AND COUNTRY

Class and country	1989		1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Arsenic trioxide:						
Australia	—	—	90	\$221	555	\$317
Belgium	1,425	\$881	1,714	1,032	1,431	964
Canada	1,771	799	—	—	—	—
Chile	5,057	1,926	6,052	2,511	6,360	3,195
China	—	—	1,132	450	7,097	3,560
Finland	414	191	963	442	661	342
France	7,059	2,977	5,399	2,485	1,297	854
Germany, Federal Republic of	17	28	147	49	18	16
Ghana	—	—	—	—	244	107
Hong Kong	18	9	70	33	643	350
Mexico	4,008	2,361	5,486	2,841	3,812	2,166
Philippines	2,727	979	2,542	944	2,813	1,164
South Africa, Republic of	94	53	380	191	—	—
Sweden	5,676	3,262	2,281	1,371	1,828	1,106
Switzerland	77	50	—	—	—	—
Taiwan	—	—	—	—	265	120
United Kingdom	5	10	—	—	(¹)	2
Other	—	—	—	—	118	57
Total²	28,348	13,526	26,256	12,570	27,142	14,320
Arsenic acid:						
Canada	15	17	1	2	—	—
Germany, Federal Republic of	—	—	3	10	—	—
Malaysia	—	—	—	—	184	128
Mexico	—	—	—	—	190	299
United Kingdom	33	50	17	19	—	—
Total	48	67	21	31	374	427
Arsenic sulfide:						
Israel	—	—	—	—	(¹)	31
Taiwan	2	19	—	—	—	—
Total	2	19	NA	NA	(¹)	31
Arsenic metal:						
Belgium	—	—	—	—	(¹)	36
Canada	85	658	7	755	7	319
China	627	649	660	2,184	635	954
France	1	1	(¹)	3	—	—
Germany, Federal Republic of	3	136	2	220	6	657
Hong Kong	124	129	94	276	71	99
Japan	74	508	8	465	29	690
Netherlands	—	—	2	4	—	—
Philippines	—	—	—	—	259	104
Taiwan	—	—	10	113	—	—
United Kingdom	14	69	13	71	(¹)	40
Total²	928	2,150	796	4,091	1,008	2,899

NA Not available.

¹ Less than 1/2 unit.

² Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 4
ARSENIC TRIOXIDE:¹ WORLD PRODUCTION, BY COUNTRY²

(Metric tons)

Country ³	1987	1988	1989	1990 ⁴	1991 ⁵
Belgium ⁶	3,500	3,500	3,500	3,500	3,000
Bolivia	132	191	338	⁷ 300	⁴ 460
Canada ⁶	² 2,000	² 2,825	¹ 1,825	⁴ 485	400
Chile	3,616	3,207	⁵ 5,000	⁵ 6,000	7,000
China ⁶	7,000	7,000	7,000	9,000	10,000
France ⁶	10,000	10,000	7,000	⁵ 6,480	3,000
Germany, Federal Republic of:					
Western states ⁶	360	360	360	360	360
Iran ⁶	1,750	370	920	340	400
Japan ⁶	500	500	500	500	500
Mexico	5,304	5,164	5,551	⁴ 4,809	⁴ 4,960
Namibia ⁵	1,864	2,983	2,399	¹ 1,610	¹ 1,804
Peru ⁶	1,757	828	563	⁵ 500	500
Philippines	6,286	5,046	4,652	5,092	5,000
Portugal	218	214	199	² 200	200
Sweden ⁷	10,000	10,000	10,000	⁷ 7,000	2,500
U.S.S.R. ⁸	8,100	8,100	8,100	7,800	7,000
Total	⁶ 2,387	⁶ 0,288	⁵ 7,907	⁵ 3,976	47,084

⁶Estimated. ⁷Revised.

¹Including calculated arsenic trioxide equivalent of output of elemental arsenic and arsenic compounds other than arsenic trioxide where inclusion of such materials would not duplicate reported arsenic trioxide production.

²Table includes data available through May 29, 1992.

³Austria, Czechoslovakia, the Eastern states of the Federal Republic of Germany, Hungary, the Republic of Korea, Spain, the United Kingdom, and Yugoslavia have produced arsenic and/or arsenic compounds in previous years, but information is inadequate to make reliable estimates of output levels, if any.

⁴Reported figure.

⁵Output of Tsuneb Corp. Ltd. only.

⁶Output of Empresa Minera del Centro del Peru (Centromin Peru) as reported by the Ministerio de Energia y Mines.

⁷Based on arsenic trioxide exported plus the arsenic trioxide equivalent of the output of metallic arsenic exported.

ASBESTOS

By Robert L. Virta

Robert L. Virta, a physical scientist with 16 years U.S. Bureau of Mines experience, has been the commodity specialist for asbestos since 1986. Domestic survey data were prepared by Joseph Daniels, statistical assistant; and international data tables were prepared by Ron Hatch, international data assistant.

The U.S. Court of Appeals for the Fifth Circuit overturned the Environmental Protection Agency (EPA) ruling that would have phased out most uses of asbestos by 1997. The court indicated the EPA did not sufficiently evaluate the health risks posed by substitutes or adequately assess the costs and benefits of less burdensome options to a total ban. Domestic asbestos production increased slightly from that of 1990, but consumption decreased 16%, from 41,348 to 34,765 tons. Asbestos was consumed domestically for roofing products, 44%; friction products, 28%; asbestos-cement pipe, 11%; packing and gaskets, 8%; and other, 9%.

DOMESTIC DATA COVERAGE

Domestic production data for asbestos are developed by the U.S. Bureau of Mines by means of a voluntary industry survey. Of the two canvassed operations to which a survey request was sent, both responded, representing 100% of the total production data shown in table 1. (See table 1.)

ANNUAL REVIEW

Legislation and Government Programs

The U.S. Court of Appeals for the Fifth Circuit overturned EPA's 1989 ruling that would have phased out most uses of asbestos by 1997. The court indicated that EPA did not adequately evaluate the health risks posed by asbestos substitutes or adequately assess the costs and benefits of alternatives to a total ban on the use of asbestos. EPA

can ban asbestos-containing products that were not manufactured or imported prior to July 12, 1989, under the court decision.¹ EPA did not appeal the decision to the U.S. Supreme Court.

EPA issued a final rule on January 30 amending national primary and secondary drinking water regulations. The maximum contaminant and maximum contaminant level goals for asbestos were both set at 7 million fibers (longer than 10 micrometers) per liter. The standard becomes effective in July 1992.²

The Mine Safety and Health Administration continued reviewing its proposed revisions to existing standards for air quality and chemical substances, including the lowering of permissible exposure levels to asbestos from 2.0 fibers per cubic centimeter to 0.2 fibers per cubic centimeter.³

The Occupational Safety and Health Administration (OSHA) issued a final rule on June 8, 1992, removing the nonasbestiform varieties of actinolite, anthophyllite, and tremolite from the scope of its asbestos standard. The nonasbestiform varieties will be regulated according to limits set for "particulates not otherwise regulated."⁴

Strategic Considerations

A wide variety of asbestos-containing civilian products also have military applications. Examples include friction materials (brakes and clutches), electrical and thermal insulations, packings and gaskets, asbestos-reinforced plastics, etc., for use on military vehicles, ships, rockets, missiles, and in military construction. During World War II and

the Korean War, strict controls were placed on the export of asbestos because the United States was dependent on foreign sources for about 90% of its requirements of all grades of asbestos. The United States was totally dependent on foreign sources for low-iron, spinning-grade chrysotile. Since that time, equipment components have been redesigned, new products have been introduced, and substitutes for asbestos are being used more frequently. Because of the trend toward lower asbestos consumption, the Department of Defense has authorized the disposal of 6,155 tons of chrysotile, 30,844 tons of amosite, and 33 tons of crocidolite from the National Defense Stockpile.

Issues

The safe use of asbestos is one of the major concerns of the asbestos industry. In response to these concerns, representatives from several countries established the International Fibre Safety Group. The purpose of the organization is to promote the safe and controlled use of asbestos and other industrial fibers and the adoption of International Labor Organization recommendations. Representatives from Belgium, Brazil, Canada, France, Thailand, the United States, the former Soviet Union, and Zimbabwe were founding members of the organization.⁵

A major concern among the public is the health risk posed by asbestos-containing materials in buildings. The Health Effects Institute-Asbestos Research, cosponsored by EPA, conducted a study of asbestos in

commercial and public buildings. The panel reported that it is unlikely that indoor asbestos concentrations would be greater than outdoor concentrations when asbestos-containing materials were in good condition. It also concluded that other pollutants posed a greater lifetime risk and that arbitrary removal of asbestos-containing material is unwarranted in well-maintained buildings.⁶ Similarly, the American Medical Association's Council of Scientific Affairs recommended the use of better management, containment, and disposal methods to prevent asbestos-related injury and disease.⁷

Production

Asbestos was produced in the United States by two companies, KCAC Inc., San Benito County, CA, and Vermont Asbestos Group Inc. (VAG), Orleans County, VT. Domestic production was limited to chrysotile, one of six commercial varieties of asbestos. KCAC operated a mine in a highly sheared serpentinite composed of matted, short-fiber chrysotile and unfractured serpentinite (also referred to as a mass fiber deposit). The ore was stripped, and wet processing was used to beneficiate the fiber. VAG operated an open pit mine in a serpentinite-containing cross-fiber veins of chrysotile. Dry milling was used to process the fiber. While the California company produced only short fiber chrysotile, the Vermont company produced a wide range of chrysotile grades.

Domestic production increased slightly from that of 1990. While domestic markets for asbestos continued to weaken, foreign markets remained strong.

Consumption and Uses

Asbestos was used in a wide variety of products because of its high tensile strength, chemical and thermal stability, high flexibility, low electrical conductivity, and large surface area. Products made from asbestos were more heat resistant (and often incombustible), more resistant to chemical attack

(particularly for alkalis), stronger (asbestos acted as a physical reinforcer), and less conductive (asbestos had a low dielectric constant). In addition, they were more viscose (asbestos stiffened compounds and coatings), faster setting (asbestos hastened water drainage in asbestos-cement pipe production), and more cost efficient than many nonasbestos products.

U.S. consumption of asbestos decreased 16% in 1991. Approximately 83% of the asbestos consumed domestically was chrysotile, 1% was crocidolite, and 16% was an unspecified fiber type, most likely chrysotile. Approximately 79% of the chrysotile consumed in the United States was grade 7, followed by grades 4, 6, 5, and 3. (See table 2.)

The construction industry is the major consumer of asbestos fiber in the form of asbestos cement pipe, asbestos cement sheet, coatings, compounds, packings, and roofing products. These end uses accounted for 70% of the asbestos consumed in the United States.

Consumption has declined dramatically from 800,962 tons in 1973 to 34,765 tons in 1991. Two factors have been responsible for the decrease. First, many U.S. markets are maturing so the demand for asbestos-containing materials has declined. Second, the controversy surrounding the health risks posed by asbestos have prompted many manufacturers to stop producing asbestos-containing products. Manufacturers gradually have been replacing asbestos with substitute materials, redesigning old products to eliminate the need for asbestos, or designing new products that require neither asbestos nor asbestos substitutes. Economic, manufacturing, performance, and/or technical difficulties were considered before asbestos was replaced by a substitute material or product.

Examples of materials substituted for asbestos include aramid fiber, calcium silicate, carbon fiber, cellulose fiber, ceramic fiber, fibrous glass, graphite flake and fiber, steel fibers, and wollastonite. Examples of alternative products include aluminum, vinyl, and wood siding; aluminum and fiberglass

sheet; asphalt coatings; ductile iron pipe; polyvinylchloride pipe; prestressed and reinforced concrete pipe, and semimetallic brakes.

Markets and Prices

The average unit value of domestically produced asbestos increased slightly from that of 1991. Unit values for imported asbestos ranged from \$154 per ton to \$1,927 per ton and averaged \$256 per ton. Unit values for exported asbestos ranged from \$169 per ton to \$2,350 per ton and averaged \$290 per ton. Approximate equivalents, in dollars per metric ton, of price ranges quoted in Industrial Minerals (London), December 1991, for Canadian chrysotile, f.o.b. mine, were \$1,320 to \$2,125 for Group 3, \$918 to \$1,275 for Group 4, \$604 to \$714 for Group 5, \$442 for Group 6, and \$136 to \$264 for Group 7. (See table 3.)

Foreign Trade

The total value of asbestos fibers and asbestos products exported and reexported from the United States was \$123,439,041. This is a slight decrease from that of 1990. Exports and reexports of brake linings and disk pads accounted for 75% of the value of all manufactured asbestos products. Canada remained the largest importer of unmanufactured fibers and manufactured products, followed by Japan, Mexico, the United Kingdom, and the Federal Republic of Germany.

Canada provided 99% of the asbestos imported into the United States, and the Republic of South Africa provided less than 1%. Zimbabwe supplied the remaining amount. Approximately 99% of the asbestos fiber imports was chrysotile. (See tables 4, 5, and 6.)

World Review

World production of asbestos, which has been fairly stable for many years, decreased again in 1991. Since 1982, production has dropped from 3,910,592 tons to 3,489,529 tons in 1991. Most of the decline occurred in the past 3 years when opposition to the use of asbestos

intensified. Consumption in more mature North American and European markets has declined. Sales in other countries continued to grow because of the need for asbestos-base construction materials.

Canada continued to be the largest market economy producer of asbestos, followed by Brazil, Zimbabwe, and the Republic of South Africa. The U.S.S.R. was the world's largest producer of asbestos. Canada and the U.S.S.R. accounted for 77% of the world production. Canada continued to be the largest exporter of asbestos. (See table 7.)

Greece.—The Northern Greece Asbestos Mines Co. in Kozani closed owing to financial difficulties. The work force at the mine was reduced from 380 to 250 employees, and the company was refinanced with Government backing. The operation may be leased to private interests in the future.⁸

South Africa, Republic of.—Msaulii Asbes Beperk, which has experienced a drop in profits in recent years, began studying the feasibility of recovering asbestos fiber from its tailings dump. The recovery would require the construction of a new mill plant.⁹

Swaziland.—The Swaziland Government and Consolidated Mining Corp. of the Republic of South Africa have taken control of the Havelock asbestos mine. Ownership is 15% and 85%, respectively. The mine is expected to have an operating life of 8 years, at a production rate of 2,500 tons per month.¹⁰

OUTLOOK

Domestic consumption will continue to decrease although the decrease should not be as great as in recent years. The overturning of the EPA phaseout of asbestos is not likely to result in a reversal of this trend. Foreign markets for asbestos fiber should remain strong because of the demand for proven, low-cost construction materials.

¹Asbestos Information Association News & Notes. The U.S. Court of Appeals for the Fifth Circuit Overturns EPA's Ban Rule on Asbestos. Oct. 25, 1991, pp. 1-4.

²Federal Register. Environmental Protection Agency. National Primary Drinking Water Regulations, Final Rule. V. 56, No. 20, Jan. 30, 1991, pp. 3526-3597.

³———. Mine Safety and Health Administration. Air Quality, Chemical Substances, and Respiratory Protection Standards. V. 56, No. 39, Feb. 27, 1991, pp. 8168-8171.

⁴———. Occupational Safety and Health Administration. Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite. V. 57, No. 110, June 8, 1992, pp. 24310-24331.

⁵Asbestos Information Association News & Notes. New International Fibre Safety Group Officially Launched in Moscow. June 28, 1991, pp. 1-2.

⁶———. Prestigious Panel Issues Long-Awaited Study on Asbestos in Public Buildings. Sept. 30, 1991, p. 1-2.

⁷Engineering News Record. Learning To Live With Asbestos. V. 227, No. 7, Aug. 19, 1991, p. 7.

⁸Mining Journal. Greece: Asbestos Mine Prop. V. 317, No. 8134, Aug. 9, 1991, p. 99.

⁹Industrial Minerals. Mining Problems Hit Msauli Asbes Beperk. No. 285, June 1991, p. 21.

¹⁰———. Havelock Asbestos Reopened. No. 286, July 1991, p. 10.

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TABLE 1
SALIENT ASBESTOS STATISTICS

	1987	1988	1989	1990	1991
United States:					
Production (sales):					
Quantity	50,600	18,233	17,427	W	W
Value ¹	\$17,198	W	W	W	W
Exports and reexports (unmanufactured):					
Quantity	60,084	31,544	27,004	27,965	25,636
Value	\$16,149	\$8,468	\$7,690	\$7,964	\$7,424
Exports and reexports of asbestos products:					
Value	\$180,602	\$194,858	\$153,081	\$120,328	\$116,015
Imports for consumption (unmanufactured):					
Quantity	93,763	85,326	55,306	41,348	34,765
Value	\$22,022	\$21,528	\$14,031	\$10,773	\$8,900
Consumption, apparent ²	84,279	71,354	*55,306	*41,348	34,765
World: Production	*4,237,122	*4,318,457	*4,237,659	*3,819,018	*3,489,529

¹Estimated. ²Revised. W Withheld to avoid disclosing company proprietary data.

³F.o.b. mine.

⁴Production, plus imports, minus exports, plus adjustments in Government and industry stocks.

⁵Does not include U.S. production.

TABLE 2
U.S. ASBESTOS CONSUMPTION BY END USE, GRADE, AND TYPE

(Thousand metric tons)

End use	Chrysotile ¹					Total ²	Cro- cido- lite	Other ³	Total asbes- tos ⁴
	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7				
1990 total	0.1	3.6	2.1	2.4	26.0	34.3	0.8	6.2	35.1
1991:									
Asbestos-cement pipe	—	2.4	.4	.6	—	3.4	.3	—	3.7
Asbestos-cement sheet	—	—	—	.9	.7	1.6	—	—	1.6
Coatings and compounds	(⁵)	—	—	—	.8	.8	—	—	.8
Friction products	(⁵)	(⁵)	.8	.4	8.3	9.5	—	—	9.5
Packing and gaskets	—	(⁵)	.6	.2	2.0	2.9	—	—	2.8
Paper	—	—	—	—	(⁵)	(⁵)	—	—	(⁵)
Plastics	(⁵)	(⁵)	(⁵)	—	—	(⁵)	—	—	(⁵)
Roofing products	—	(⁵)	—	(⁵)	15.1	15.1	—	—	15.1
Other	(⁵)	.4	(⁵)	—	.2	.6	—	—	.6
Total ²	(⁵)	2.7	1.8	2.1	27.0	33.8	.3	.5	34.0

¹Estimated distribution based upon data provided by the Asbestos Institute, Montreal, Canada, and the U.S. Bureau of Mines asbestos producer survey.

²Data may not add to totals shown because of independent rounding.

³Source: Bureau of the Census. "Other" category contains unspecified fiber type and end use.

⁴Does not include "Other" category in total.

⁵Less than 1/10 unit.

**TABLE 3
CUSTOMS UNIT VALUES OF IMPORTED ASBESTOS**

(Dollars per metric ton)

	1987	1988	1989	1990	1991
Canada:					
Chrysotile:					
Crude	610	635	167	782	776
Spinning	598	756	387	291	372
Other	218	227	227	259	265
South Africa, Republic of:					
Amosite	—	—	3,728	—	—
Crocidolite	572	609	631	651	582

Source: Bureau of the Census.

**TABLE 4
COUNTRIES IMPORTING U.S. ASBESTOS FIBERS AND PRODUCTS**

(Thousand dollars)

Country	1990			1991		
	Unmanufactured fiber	Manufactured products	Total ¹	Unmanufactured fiber	Manufactured products	Total ¹
Australia	12	1,851	1,863	10	1,083	1,093
Brazil	534	4,171	4,705	433	2,914	3,348
Canada	472	58,458	58,930	366	50,833	51,199
Germany, Federal Republic of	63	5,479	5,542	58	3,363	3,421
Japan	4,119	10,938	15,057	3,758	11,395	15,154
Korea, Republic of	107	1,477	1,584	386	2,513	2,899
Kuwait	—	189	189	—	51	51
Mexico	529	5,822	6,350	1,259	7,652	8,910
Saudia Arabia	14	1,047	1,061	10	3,278	3,289
Thailand	81	280	360	58	261	320
Turkey	—	92	92	—	64	64
United Kingdom	134	6,517	6,650	21	4,829	4,850
Venezuela	13	712	725	—	259	259
Other	1,888	23,295	25,185	1,064	27,520	28,524
Total¹	7,964	120,328	128,292	7,424	116,015	123,439

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 5
U.S. EXPORTS AND REEXPORTS OF ASBESTOS AND ASBESTOS
PRODUCTS

Products	Quantity	Value (thousands)
1990:		
Unmanufactured:		
Asbestos ¹ tons	27,965	\$7,964
Manufactured:		
Asbestos fibers do.	81	684
Brake linings and disk brake pads ²	NA	93,125
Clutch facings and linings ³ tons	NA	7,242
Clothing, cord, fabric, and yarn	NA	1,376
Gaskets, packing and seals tons	NA	4,565
Panel, sheet, tile, and tube ⁴ do.	NA	4,109
Paper and millboard	NA	885
Other articles ⁵	NA	8,341
Total⁶	XX	120,328
1991:		
Unmanufactured:		
Asbestos ¹ tons	25,636	7,424
Manufactured:		
Asbestos fibers do.	NA	772
Brake linings and disk brake pads ²	NA	86,980
Clutch facings and linings ³ tons	NA	6,637
Clothing, cord, fabric, and yarn	NA	724
Gaskets, packing and seals tons	NA	6,841
Panel, sheet, tile, and tube ⁴ do.	NA	4,651
Paper and millboard	NA	1,155
Other articles ⁵	NA	8,254
Total⁶	XX	116,015

NA Not available. XX Not applicable.

¹Includes crudes, fibers, stucco, sand, refuse.

²Includes asbestos and cellulose fiber brakes and similar materials.

³Includes clutches and other friction materials, excluding brakes and brake pads.

⁴Includes asbestos-cement and cellulose fiber cement products.

⁵Includes asbestos and cellulose fiber products.

⁶Data may not add to totals shown because of independent rounding.

TABLE 6
U.S. IMPORTS FOR CONSUMPTION OF ASBESTOS FIBERS, BY TYPE, ORIGIN, AND VALUE

Type	Canada		South Africa, Republic of		Other		Total ¹	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
1989	<u>53,572</u>	<u>\$12,961</u>	<u>1,040</u>	<u>\$628</u>	<u>694</u>	<u>\$442</u>	<u>55,306</u>	<u>\$14,031</u>
1990:								
Chrysotile:								
Crude	188	137	—	—	17	23	205	160
Spinning fibers	840	185	—	—	58	77	898	261
All other	33,164	8,542	—	—	58	77	33,222	8,619
Crocidolite (blue)	—	—	835	544	—	—	835	544
Other (unspecified asbestos type)	6,188	1,188	—	—	—	—	6,188	1,188
Total ¹	<u>40,380</u>	<u>10,052</u>	<u>835</u>	<u>544</u>	<u>133</u>	<u>177</u>	<u>41,348</u>	<u>10,772</u>
1991:								
Chrysotile:								
Crude	176	137	—	—	—	—	176	137
Spinning fibers	683	193	—	—	53	81	736	274
All other	27,872	7,356	—	—	23	37	27,895	7,393
Crocidolite (blue)	73	12	209	152	—	—	282	164
Other (unspecified asbestos type)	5,676	932	—	—	—	—	5,676	932
Total	<u>34,480</u>	<u>8,630</u>	<u>209</u>	<u>152</u>	<u>76</u>	<u>118</u>	<u>34,765</u>	<u>8,900</u>

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 7
ASBESTOS: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991 ³
Argentina	332	2,328	225	*300	250
Brazil	212,807	227,653	206,195	*210,000	210,000
Bulgaria	400	*300	*300	*300	300
Canada (shipments)	664,546	710,357	701,227	*685,627	*686,867
China	144,673	157,478	*160,000	*160,000	150,000
Colombia ⁴	6,600	7,600	7,900	8,000	8,000
Cyprus	18,070	14,585	—	—	—
Egypt	209	166	312	*369	350
Greece	60,134	*71,114	72,500	*65,600	60,000
India	29,110	31,123	36,502	*25,958	30,000
Iran ³	*2,900	3,400	*3,300	*3,300	3,300
Italy	118,352	94,549	*44,348	*3,862	3,500
Japan	*5,207	*5,000	*5,000	*5,000	5,000
Korea, Republic of	2,518	2,428	2,361	*1,534	1,500
South Africa, Republic of	135,074	145,678	*156,594	*145,791	*148,962
Swaziland	25,925	22,804	27,291	*35,938	15,000
Turkey	806	*50	—	—	—
U.S.S.R. ³	*2,554,600	2,600,000	2,600,000	2,400,000	2,000,000
United States (sold or used by producers)	50,600	18,233	17,427	W	W
Yugoslavia	10,964	17,030	*9,111	*6,578	5,500
Zimbabwe	193,295	186,581	187,066	*60,861	161,000
Total	*4,237,122	*4,318,457	*4,237,659	*3,819,018	3,489,529

²Estimated. ³Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

¹Marketable fiber production. Table includes data available through Apr. 16, 1991.

²In addition to the countries listed, Afghanistan, Czechoslovakia, North Korea, and Romania also produce asbestos, but output is not officially reported, and available general information is inadequate for the formulation of reliable estimates of output levels.

³Reported figure.

⁴Estimated fiber production based on reported crude production, in metric tons, of: 1987—132,723; 1988—152,896; 1989—158,149; 1990—160,000 (estimated); 1991—160,000 (estimated).

BARITE

By James P. Searls

Mr. Searls, a physical scientist and economist with 15 years of institute, Government, and U.S. Bureau of Mines experience, is the commodity specialist for barite. Domestic survey data were prepared by Maria Rosa Arguelles, statistical assistant; and international data were prepared by Virginia Woodson, international data coordinator.

Domestic production of barite increased 4% to 448 thousand metric tons¹ while apparent consumption decreased 12% to about 1.27 million tons. Exports rose fourfold to 43,000 tons while imports declined about 14% to 841 thousand tons. Production from Nevada was about 78% of the U.S. total. Twelve production facilities closed during the year, but the remaining facilities increased output, which kept the total production slightly above that of 1990. The principal use for barite, as a weighing agent in oil- and gas-well-drilling fluids (muds), accounted for 92% of U.S. apparent consumption. In 1991, oil prices trended downward to a range that did not encourage deep drilling (below 10,000 feet) for oil and gas. Deep drilling declined 13% while total oil and gas wells drilled rose by 13%.

DOMESTIC DATA COVERAGE

Domestic production data for barite are developed by the U.S. Bureau of Mines from a voluntary survey of U.S. operations. Of the 55 operations to which a survey request was sent, all responded, representing 100% of the crushed and ground production sold or used shown in table 1. (See tables 1 and 2.)

BACKGROUND

Definitions and Specifications

The term "primary barite," as used in this report, refers to the first marketable product and includes crude barite, flotation concentrate, and other

beneficiated material such as washer, jig, heavy media, table, or magnetic separation concentrate. Most primary barite requires fine grinding before it is used for drilling muds. This grinding may or may not be done at the mine site.

Barite is the mineralogical name for barium sulfate and was derived from the Greek word "barus," meaning heavy. In commerce, the mineral is often referred to as "heavy spar" or "barytes." "Spar" means almost any transparent or translucent, readily cleavable, crystalline mineral having a vitreous luster.² Specifications for barite vary according to different uses. Material for weighing muds must be finely ground, dense, and chemically inert; consequently, barite for this purpose must have a specific gravity of 4.2 or higher, it must be free of soluble salts, and 90% to 95% of the material must pass through a 325-mesh screen. A small percentage of iron oxide is not objectionable. In chemical manufacturing, purity is the principal concern, and a maximum of 1% each of ferric oxide (Fe_2O_3) and strontium sulfate (SrSO_4) and a trace of fluorine usually are specified, with a minimum of 94% barium sulfate (BaSO_4). If the mineral is to be used in the production of lithopone, the SrSO_4 content may be somewhat higher. Mesh size is important to chemical manufacturers; if the material is too fine, dust is lost, and if it is too coarse, mixing with carbonaceous material is poor. Most chemical manufacturers specify a size range of 4 to 20 mesh; some purchase lump barite and grind it to their own needs.

Products for Trade and Industry

The principal use for barite, as a weighing material in well drilling muds, accounted for more than 92% of total U.S. consumption in 1991. Drilling muds have five main functions: (1) transport drill cuttings to the surface, (2) control formation pressures, (3) maintain borehole stability, (4) protect producing zones, and (5) cool and lubricate the bit and drill string. Barite's lack of hardness (Mohs scale 2 to 3.5) is a plus in this application. The principal function of the barite constituent is as a weighing agent to suppress high formation pressures and prevent blowouts. The deeper the hole, the more barite is needed as a percentage of the total mud mix because hydrocarbon pressures rise strongly with increasing depth. The added weight of the barite in the column of mud is used to counteract the dangerous pressures when deep pockets of hydrocarbons are encountered. High-pressure hydrocarbons can cause extremely dangerous explosions or fires at the drilling rig if uncontrolled.

The use of barite as a filler or extender and other uses accounted for about 7% of total U.S. consumption in 1990. Barite has a high specific gravity, low oil absorption, easy wettability by oils, and good sanding qualities. Unbleached barite may be substituted for bleached barite when brightness is not a factor. In painting automobiles, barite is used as a filler for the primer coats. The barite contributes to the gloss of the topcoat. When the primers are applied by the electrodeposition process, the body structure is dipped into a tank containing water and paint primer. The method

eliminates one of the primary coats, thus reducing the quantity of barite used.

Barite is also used as a filler or extender in some plastic and rubber products. Processors of polyurethane foam use barite in manufacturing such products as floor mats and carpet-backings to add weight and improve processing qualities. Barite is used in white sidewalls for tires; sidewalls consist mainly of rubber, zinc oxide, and a small quantity of barite.

Other industries use small quantities of barite fillers. In the paper industry, the white and dense barite coatings serve as a base for the sensitized layers in photographic prints. In the printing industry, barite is used in inks.

In glassmaking, barite is added to the glass melt to reduce the heat-insulating froth that forms on the melt surface, thus saving fuel, and to act as an oxidizer and decolorizer, making the glass more workable and increasing its brilliance. Glass manufacturers usually require a minimum of 95% BaSO_4 with a maximum of 2.5% silicon dioxide (SiO_2) and 0.15% Fe_2O_3 . The particle size range generally preferred is -30 to +140 mesh. Finely ground barite can be substituted when crushed material is not available. Barium-base glass (using barium carbonate) is considered to be more brilliant than lime glass and more durable than lead glass.

Minor uses include ballast for ships, heavy concrete aggregate for radiation shielding and pipe-weighting in low-lying areas, friction products, and applications in foundries.

Barite is also a raw material for barium chemical manufacturing. The major barium chemicals are the carbonate, chloride, oxide, hydroxide, nitrate, peroxide, and sulfate.

The most important barium chemical is precipitated barium carbonate, which is a raw material for production of many of the other compounds. It is also used in brick and tile manufacturing to control scum caused by gypsum or magnesium sulfate in the clay and to diminish porosity and prevent discoloration in brick. Other uses are in television picture tubes as a radiation barrier,

optical glass, ceramic glazes, porcelain enamel, ferrites, and miscellaneous ceramic products.

Blanc fixe, chemically precipitated barium sulfate, is used as a white filler in paints, rubber, inks, and other materials where a degree of purity higher than natural barite is required. Lithopone (a white pigment composed of a mixture of barium sulfate, zinc sulfide, and zinc oxide), formerly manufactured in large tonnages for use as a white pigment in paints, has been largely replaced by titanium dioxide.

Barium chloride is used in case-hardening and heat-treating baths, in leather and cloth, in making magnesium metal, in preventing scum on brick, in water treatment, and as a laboratory reagent. Fused barium chloride may be electrolyzed to produce barium metal.

Barium nitrate is used in green signal flares, tracer bullets, primers and detonators, and enamels. Barium oxide is used in electric furnace ferrous metallurgy to increase the life of acid furnace linings, to give a quieter and steadier arc, to reduce the sulfur content of the iron, and to lower the slag viscosity.

Barium hydroxide is used to make barium stearate for lubricating greases. Barium-base greases are excellent for load bearing, water resisting applications. It is also used as a rust preventative because it is extremely sticky and resistant to even steam cleaning. Barium titanate finds use in miniature electronic and communication equipment.

Barium metal is also produced by reduction of barium oxide. The metal is used as a "getter" to remove traces of gas from vacuum tubes, or in alloys for spark plugs and electronic emission elements in electronic tubes.

Industry Structure

Domestic barite production began in 1845 in Fauquier County, VA. About 5 years later, production began in Missouri. In 1880, Tennessee became the third barite-producing State, and 1901 and 1903 saw Georgia and Kentucky, respectively, become producers.

California began producing in 1914, Nevada in 1916, and Arkansas in 1941.

Barite was first used as a filler in white paints; however, in 1842, with the advent of the domestic lithopone industry, a second important market opened. In 1908, Chicago Copper Refining Co. began manufacturing barium chemicals at Blue Island, IL. The first washers and jigs used in the industry were installed in Georgia and Tennessee in 1914-16 and in Missouri in 1923-24. A fourth market for barite came into existence in 1916 when a patent was obtained on the use of barite as a weighing agent in rotary drilling muds; today this is the largest consumer of barite. In 1941, the deposit of barite at Malvern, AK, was opened when Magnet Cove Barium Corp. successfully separated barite from associated minerals by flotation. In 1977, IMCO Services Co. completed a multimillion dollar plant at Mountain Springs, NV, that produced barite concentrate using jigs, concentration tables, and flotation. This combination of beneficiating methods was unique in the barite industry.

Geology

Barite is the only commercial source of barium and barium compounds in the United States. Witherite (BaCO_3) has been produced from the Settlingstones Mine in England, and small quantities enter the United States every year.

Pure barite has a specific gravity of 4.5. Barite varies considerably in appearance depending on source and treatment. It is a moderately soft crystalline material with a Mohs' hardness between 2 and 3.5. In residual deposits, it ranges in size from large boulders to fines. Shades of white to dark gray and black, depending on impurities and surficial coating, are common in commercial deposits.

Vein and cavity-filling deposits are those in which barite occurs along faults, joints, bedding planes, and other solution channels or sink structures. These deposits are found most often in limestone. Most of the vein deposits are believed to be of hydrothermal origin.

In central Missouri, barite occurs in circular deposits in karst or collapse and sink structures. These ores are rich, but the deposits are generally small in overall extent. These deposits are also important as the source of the residual ore upon weathering.

Residual barite deposits are formed by weathering of preexisting deposits. The principal residual deposits are found in southeastern Missouri; the Appalachian region; Sweetwater, TN; Cartersville, GA; and in the Rio Grande area of Texas. A concentration of at least 100 to 300 pounds of barite per cubic yard is required in a commercial deposit. In Washington County, MO, the residuum is 10 to 15 feet thick, while in Cartersville, GA, the ore is 150 feet thick in some spots. This form of deposit has been of considerable economic significance.

The most important commercial deposits are of bedded barite. These are principally in Arkansas, California, and Nevada. The barite in these areas is generally dark gray to black and has a characteristic fetid odor when struck with a hammer. The beds, which vary in thickness from several inches to more than 50 feet, occur interbedded with dark chert and siliceous siltstone and shale. In most of the deposits, the barite is laminated. In some areas, barite nodules and rosettes make up a large part of the beds. Many of the beds contain 50% to 95% barite. Originally it was thought that these deposits were the result of the replacement of carbonate rocks; however, current thought is that the deposits are of sedimentary origin. The actual environment of deposition has not been established, but theories range from submarine volcanic emissions to hydrothermal solutions to recycling of barite from preexisting rocks.

Technology

Exploration.—In the past two decades, geological exploration has led to the discovery of bedded barite deposits in Canada, India, Mexico, and the United States. Bedded deposits have not been sought in many parts of the world. As the search for barite expands in the

coming years, it is likely that more bedded deposits will be discovered.

Mining.—Residual deposits of barite are generally mined by draglines in open pits after removal of overburden by conventional methods using elevating scrapers, trucks, dumpers, bulldozers, and front-end loaders. The ore is then beneficiated in washer plants equipped with rotary breakers, log washers, trommel screens, and jigs to separate barite from other material. Fine barite in the overflow from the log washers is recovered by tabling and flotation while the jig concentrate is magnetically separated.

Bedded and vein deposits may be mined by open pit or underground methods depending on local conditions. The bedded deposits of Arkansas have been mined by both methods. The ore is crushed and ground for beneficiation by flotation. Bedded barite in Nevada is mined by open pit methods using a combination of bulldozers with ripping teeth and conventional blasting. The ore is picked up by front-end loaders and hauled in dump trucks to a processing plant. In some deposits, the ore is of sufficient grade to be either screened and direct shipped or washed, crushed, screened, and shipped to a grinding plant; however, much of the ore requires beneficiation by jigging or flotation.

Quantities of barite have been recovered by underwater mining off Castle Island near Petersburg in southeastern Alaska. The ore is blasted, recovered by a crane equipped with a special digging bucket, and loaded into barges.

Processing.—Barite grinding is usually accomplished by heated airswept Raymond mills, a type of roller mill; however, ball mills are used when iron contamination is not important, as in drilling muds. Barite is ground either wet or dry. For use in well drilling, barite is ground dry. If the barite requires upgrading by flotation, it is ground wet. Barite is also ground wet when it is to be bleached for filler use; impurities are subsequently removed by

treatment with sulfuric acid. The bleached barite pulp is then settled and separated, washed, dried, sized, and bagged.

A small amount of barite is converted into a soluble form before its use in the manufacture of lithopone or other chemicals. Crushed barite is roasted with coke in a kiln at about 1,200° C to reduce the barium sulfate to the more soluble compound, barium sulfide, commonly called black ash. The sulfide is leached from the clinker with hot water. By adding zinc sulfate to the leach liquor, an intimate mixture of barium sulfate and zinc sulfide called lithopone is precipitated.

The leach liquor is also a precursor of a number of barium chemicals. Addition of sodium sulfate precipitates a pure barium sulfate (called blanc fixe). Barium carbonate is precipitated by either carbonating or adding sodium carbonate to the leach liquor. Hydrochloric acid added to the leach liquor produces a solution of barium chloride. Barium carbonate and barium chloride are the starting compounds for the manufacture of many other barium chemicals.

ANNUAL REVIEW

Legislation and Government Programs

The U.S. Environmental Protection Agency (EPA) announced the discovery of a series of anaerobic and aerobic processes that could conceivably occur in a hydrocarbon drill site waste pit and convert inert barite to a form with mobile barium ions. Barium ions, when mobile, are considered to be a toxic heavy metal.

Production

Run-of-mine barite output, the lowest cost primary barite sold or used by producers and representing 65% of total production, decreased 7% from that of 1990. The remainder of total production was flotation concentrate and other beneficiated material. The lower cost crude barite and jigged beneficiated materials were used chiefly in drilling

muds; the higher valued floated and other beneficiated material was used mostly in chemical and glass manufacturing and in filler applications.

Reported primary production increased almost 4% from a revised 430,000 tons in 1990. Nevada and Georgia remained the two leading barite-producing States. Other producing States, in descending order, were Missouri, California, Illinois, and Montana. Illinois production was as a coproduct of fluor spar mining and milling; in all other States, barite is the primary product.

The leading domestic barite producers were M-I Drilling Fluids Co., a Dresser-Halliburton Co. division, with mines in Nevada; Milpark Drilling Fluids, a Baker Hughes Inc. division, also with mines in Nevada; and Baroid Drilling Fluids Inc., a NL Petroleum Services Inc. division, with mines in Missouri and Nevada. (See tables 3 and 4.)

Consumption and Uses

Consumption of crushed and ground barite decreased about 12% to 1.3 million tons in 1991. The oil- and gas-well-drilling industry completed less than 22,000 wells of all types³ and drilled almost 112 million feet of hole,⁴ which represented an 8% and 11% increase, respectively, compared with those of 1990. The relationship between barite production, consumption, and well drilling, especially deep well drilling, is illustrated in figure 1. (See figure 1.)

Note that there is a generally common shape between the tops of the barite tonnage bars and the number of wells drilled below 10,000 feet curve. The regression of "total number of wells drilled" (not shown) on "tons of barite used" results in an R^2 (adjective) of .76 while the regression of "number of wells drilled below 10,000 feet" and "year" on "tons of barite used" results in an R^2 (adjective) of .82 for 21 years of data. The "component plus residual" plot for time (year) shows a downward trend for barite. Apparently the well drilling industry has learned to use less barite per well over time.

Total drilling footage exceeded 6 million feet in four States: Texas, 46.9 million feet; Oklahoma, 12.3 million; Louisiana, 9.0 million; and Kansas, 7.0 million. Generally, the deeper a hole is drilled after 5,000 feet, the more barite is used per foot of drilling.

Another barometer of drilling activity at the end of 1991, the Baker Hughes rig count, showed the cumulative average number of operating domestic rigs in 1991 decreased almost 15% to 859. The end of the year count was 770, below the yearly cumulative average.⁵ The Smith rig count, from the same source, reported 310 rigs drilling to below 10,000 feet, down 31% from 1990's count of 451 rigs at the end of the year.

The low rig count at the end of the year can be explained by the generally low price of oil. This price is discussed using a common marker grade, West Texas Intermediate. West Texas Intermediate oil reached a peak price of about \$37 per barrel in October 1990 then fell continuously to below \$20 per barrel in March 1991.⁶ West Texas Intermediate oil prices then trended up to a high point of about \$24 per barrel in October and fell below \$20 per barrel by the end of the year. Saudi Arabia, the United Arab Emirates, and Venezuela had increased their production in the latter half of 1990 to make up for lost production during the Iraqi invasion of Kuwait and the loss of Kuwaiti and Iraqi oil on the world market. "With lost production replaced, formerly idle capacity in use, and demand stalling for economic reasons, the market spent 1991 nearly in balance, which moderated the volatility characteristic of crude prices in recent years."⁷ "Estimated" total well drilling in the United States declined from about 7,800 wells in the first quarter to 6,450 wells in the fourth quarter of 1991, according to the American Petroleum Institute. (See tables 5 and 6.)

Prices

Price quotations in such trade publications as the Chemical Marketing Reporter, Industrial Minerals, and Engineering and Mining Journal for barite

remained unchanged throughout the year. The quoted prices are in nominal dollars and do not show any increase to reflect inflation. The quoted prices may serve as a general guide but do not reflect actual transactions, some of which are on long-term contracts and some are at confidential, negotiated prices.

The reported average value per ton of domestic barite, based on reported value of direct-ship, beneficiated, and floated material, increased almost 28%, f.o.b. plant, from \$37.21 per ton in 1990 to \$47.57. The average value of ground barite, sold or used by producers, was \$81.24 per ton, a 6% decrease from the \$86.36 per ton reported in 1990. Within this group the average value of barite for well drilling end use was \$75.45 per ton while the average value for barium chemicals, filler and extender, and glass, was \$148.08 per ton. The average customs value of exported barite was \$76.84 per ton. The average c.i.f. value of imported crude barite was \$43.67 per ton, and the c.i.f. value of imported ground barite from Mexico was \$65.55 per ton.

Foreign Trade

Exports of natural barium sulfate or barite increased strongly from about 9,200 tons to about 43,300 tons. Export data provided by the Bureau of the Census did not indicate the grades of barite traded; however, based only on the dollars per ton of individual shipments, which varies from about \$40 to almost \$2,000 per ton, drilling-, filler-, glass-, chemical-, and pharmaceutical-grade were all exported. Historically, barite exports were predominantly ground drilling-mud-grade material with less than 5% of the tonnage as specialty ground barites. Canada and Mexico have been traditionally either first or second among export recipients of U.S. ground barite, but Brazil received the largest quantity in 1991 and Venezuela was second. (See table 7.)

Imports for consumption of crude barite declined about 15% from those of 1990 to less than 0.9 million tons. The principal source countries, in descending

order, were China at 710,000 tons of crude barite, India at 123,000 tons of crude barite, and Mexico at 37,000 tons of ground barite. The higher priced material was chiefly crude filler and extender-quality barite. High-quality barite, generally material with a specific gravity greater than 4.2, is usually blended during grinding with lower grade ore, foreign or domestic, to meet American Petroleum Institute specifications for a minimum density of 4.2 for drilling-mud-grade barite. Most of the crude barite entered through customs districts along the gulf coast for delivery to grinding plants in the area. (See tables 8, 9, 10, and 11.)

World Review

Capacity.—The data in table 13 are rated capacity for mines as of December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period with minimum capital expenditure.

Mine capacity for domestic barite production was aggregated from data voluntarily supplied by the producers. The rated capacity data for the foreign mines were estimated from the previous year's production in cooperation with the Division of International Minerals. (See tables 12 and 13.)

Little change occurred around the world as China, India, and Morocco dominated the international market with large capacity and good quality, low-priced product.

United Kingdom.—Minworth Group went into receivership early in the year due to losses at the Strontian Mine (and involvement in a fluorspar mine).

OUTLOOK

With the end of the Persian Gulf War and confidence in the continuation of world peace and the tranquility of world oil supplies and prices, the demand for drilling rig usage is declining. Saudi Arabia and Kuwait may be interested in keeping oil prices relatively low over the next several years in appreciation of the war fought on their behalf by many countries from around the world. They may also know that higher oil prices will bring in other technologies and fuel sources in the long run, so they may be interested in letting a free market establish oil prices. Demand for petroleum products may be sluggish as several large countries deal with financial problems. The United States must pay for the savings and loan bailout, infrastructure replacement, environmental concerns, and social concerns. Japan has had its own contraction in the stock market and banking circles that may leave it short of cash for several years. The Federal Republic of Germany must put much of its cash into reintegrating the former East Germany and replacing its infrastructure and capital goods for future production and environmental protection. The Commonwealth of Independent States, formerly the U.S.S.R. and countries of East Europe, have to reorganize their economic systems, form entrepreneurial groups, and invest in large amounts of capital goods to reemploy, even retrain, millions of workers. World economic growth may be slow for several years as these several problems are worked through, meaning slow growth in petroleum consumption and prices that will not encourage aggressive drilling for new reserves. Slow growth in petroleum consumption will lead to less drilling and lowered demand for barite, tempered by the search for ever deeper new resources that do use more barite.

The U.S. Department of Energy (DOE) has forecast crude oil prices out to the year 2010 recently.⁸ A simple regression of barite consumption for hydrocarbon well drilling on (U.S. Refiner's

Acquisition Cost of Imported Crude Oil) oil prices was performed. The R^2 equaled 0.827 for the regression. The forecast into the future for the DOE model considered \$23 per barrel (1990 \$s) for a low case, \$33 per barrel for a medium case, and \$40 per barrel for a high case by the year 2010. The corresponding barite demand quantities would increase smoothly from 1990's consumption level of 1,409,000 tons to 1,626,000 tons of barite per year for \$23 per barrel in the year 2010, 2,277,000 tons of barite for \$33 per barrel in the year 2010, and 2,733,000 tons of barite per year for \$40 per barrel in the year 2010.

¹All tonnages are reported in metric tons, unless otherwise noted.

²U.S. Department of the Interior. A Dictionary of Mining, Mineral, and Related Terms. P. W. Thrush, (ed.). U.S. GPO, Washington, DC, 1968, p. 1049.

³Excluding service wells, stratigraphic tests, and core tests.

⁴American Petroleum Institute. Quarterly Review of Drilling Statistics for the United States. 4th Quarter 1991, and Annual Summary 1991, v. 7, No. 4, Feb. 1992, p. 5.

⁵Oil & Gas Journal. PennWell Publishing Co., Tulsa, OK, v. 90, No. 1, Jan. 6, 1991, p. 96.

⁶Vielvoe, R. World Oil Prices In Jeopardy, Oil & Gas J., v. 90, No. 2, Jan. 13, 1992, pp. 14-17.

⁷Oil & Gas Journal. Oil Production Triggered by Crisis Stays on Stream Throughout '91. V. 89, No. 52, Dec. 1991, p. 43.

⁸Energy Information Agency. Annual Energy Outlook: 1992—With Projections to 2010, U.S. GPO, Washington, DC, DOE/EIA - 0383 (92), p. 6

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World Mining.

TABLE 1
SALIENT BARITE AND BARIUM CHEMICAL STATISTICS

(Thousand metric tons and thousand dollars)

	1987	1988	1989	1990	1991
United States:					
Barite, primary:					
Sold or used by producers	406	404	290	*430	448
Value	\$15,810	\$15,512	\$12,625	*\$16,000	\$21,310
Exports	9	(¹)	10	9	43
Value	\$716	\$353	\$1,622	\$1,675	\$3,304
Imports for consumption (crude)	748	1,132	987	988	841
Value	\$27,162	\$43,438	\$39,768	\$40,103	\$35,883
Consumption (apparent)²	1,147	1,536	1,271	*1,409	1,246
Crushed and ground (sold or used by processors)³	1,301	1,612	1,277	1,434	1,267
Value	\$108,759	\$127,373	\$103,759	\$99,562	\$102,934
Barium chemicals (sold or used by processors)	28	27	*30	W	W
Value	\$16,466	\$15,284	*\$17,000	W	W
World: Production	*4,608	*5,466	*5,574	*5,595	*5,271

*Estimated. ¹Revised. W Withheld data to avoid disclosing company proprietary data.

¹Less than 1/2 unit.

²Sold or used plus imports minus exports.

³Includes imports.

TABLE 2
PRODUCERS OF BARIUM MATERIALS IN 1991

Company	Plant location	Material
BARITE		
American Minerals Inc.	Camden, NJ	Filler and well drilling.
Do.	Rosiclare, IL ¹	Do.
Baroid Drilling Fluids Inc.	Fountain Farm, MO ¹	Do.
Do.	Lake Charles, LA	Do.
Do.	New Orleans, LA	Do.
Circle A Construction Co. Inc.	Wells, NV ¹	Primary and filler.
Custom Milling & Supply Co.	Salt Lake City, UT	Well drilling.
Cyprus Industrial Minerals Co.	Cartersville, GA ¹	Primary and ground.
GEO International Inc.	Florin, CA	Do.
International Drilling Fluids	Amelia, TX	Well drilling.
J. M. Huber Corp.	Quincy, IL	Do.
M-I Drilling Fluids	Battle Mountain, NV ¹	Do.
Do.	Brownsville, TX	Well drilling and filler.
Do.	Galveston, TX	Well drilling.
Do.	Lander, NV ¹	Primary and ground.
Do.	New Orleans, LA	Well drilling.
Do.	West Lake Charles, LA	Well drilling and filler.
Do.	Ross, NV ¹	Primary.
Milpark Drilling Fluids	Argenta, NV ¹	Primary and ground.
Do.	Corpus Christi, TX	Do.
Do.	Galveston, TX	Do.
Do.	New Orleans, LA	Do.
The Milwhite Co. Inc.	Brownsville, TX	Well drilling and filler.
Do.	Houston, TX	Well drilling.
Harcros Pigment Inc.	East St. Louis, IL	Filler.
Mountain Minerals Co., Ltd.	Missoula, MT ¹	Primary and ground.
New Riverside Ochre Co.	Cartersville, GA ¹	Primary.
Old Soldiers Minerals Ltd.	Abbeville, LA	Well drilling.
Do.	Elk City, OK	Do.
Ozark-Mahoning Co.	Rosiclare, IL ¹	Primary.
Standard Industrial Minerals	Laws, CA	Filler.
Standard Slag Inc.	Nye, NV ¹	Do.
BARIUM COMPOUNDS		
J.T. Baker Chemical Co.	Phillipsburg, NJ	Chemicals.
Chemical Products Corp.	Cartersville, GA	Do.

¹Barite mines.

TABLE 3
U.S. PRIMARY BARITE SOLD OR USED BY PRODUCERS, BY STATE

State	Number of operations	Run of mine		Beneficiated material		Total	
		Quantity (thousand metric tons)	Value (thousands)	Quantity (thousand metric tons)	Value (thousands)	Quantity (thousand metric tons)	Value (thousands)
1990:							
Nevada	6	294	\$5,116	44	\$768	338	\$5,884
Other States	8	17	1,056	91	8,913	¹ 193	¹ 10,116
Total	14	311	6,172	135	9,681	²430	²16,000
1991:							
Nevada	5	288	5,449	87	6,485	374	11,933
Other States	5	3	162	71	9,215	74	9,377
Total¹	10	290	5,611	157	15,699	448	21,310

¹Revised.

²Data may not add to totals shown because of independent rounding.

TABLE 4
CRUSHED AND GROUND BARITE¹ SOLD OR USED BY PROCESSORS IN THE UNITED STATES, BY STATE

State	1990			1991		
	Number of plants	Quantity (thousand metric tons)	Value (thousands)	Number of plants	Quantity (thousand metric tons)	Value (thousands)
Louisiana	7	700	\$56,895	7	655	\$47,450
Missouri	2	W	W	2	W	W
Nevada	3	144	9,680	3	216	15,401
Oklahoma	1	W	W	1	W	W
Texas	7	388	33,905	6	276	24,755
Other ²	19	202	23,356	9	118	15,328
Total	39	1,434	123,836	28	³1,267	102,934

W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Includes imports.

²Includes Arkansas (1990), California, Georgia, Illinois, New Jersey, and Utah.

³Data do not add to total shown because of independent rounding.

TABLE 5
CRUSHED AND GROUND BARITE¹ SOLD OR USED BY PROCESSORS IN THE UNITED STATES, BY USE

(Thousand metric tons and thousand dollars)

Use	1990		1991	
	Quantity	Value	Quantity	Value
Barium chemicals, filler and/or extender, glass	105	16,758	100	14,808
Well drilling	1,329	107,078	1,168	88,126
Total	1,434	123,836	²1,267	102,934

¹Includes imports.

²Data may not add to total shown because of independent rounding.

TABLE 6
U.S. HYDROCARBON WELL DRILLING AND BARITE CONSUMPTION

Year	Barite used for well drilling (thousand metric tons)	Wells drilled (thousands) ¹				Wells below 10,000 feet	Average barite per well (metric tons)
		Oil	Gas	Dry holes	Total		
1971	947	11.86	3.83	10.16	25.85	2,412	40.39
1972	1,073	11.31	4.93	11.06	27.30	2,757	43.33
1973	1,203	9.90	6.39	10.31	26.60	2,572	49.85
1974	1,306	12.78	7.24	11.67	31.69	2,598	45.44
1975	1,486	16.41	7.58	13.25	37.24	2,953	43.98
1976	1,802	17.06	9.09	13.62	39.77	3,091	49.94
1977	2,152	18.91	11.38	14.69	44.98	3,582	52.73
1978	2,388	17.76	12.93	16.25	46.94	4,241	56.07
1979	2,692	19.38	14.68	15.75	49.81	4,516	59.57
1980	3,071	26.99	15.74	18.09	60.82	5,083	55.66
1981	4,106	37.67	17.89	22.97	78.53	6,570	57.63
1982	3,672	40.30	18.95	26.55	85.80	6,891	47.18
1983	2,402	37.21	15.63	23.49	76.33	5,029	34.69
1984	2,445	41.10	15.71	25.23	82.04	5,865	32.85
1985	1,852	26.24	10.15	15.97	52.36	3,402	39.00
1986	995	15.27	5.53	10.28	31.08	3,257	35.30
1987	1,174	12.13	4.97	9.04	26.14	2,803	49.50
1988	1,401	10.54	5.54	8.42	24.50	3,049	63.02
1989	1,175	7.73	6.16	6.89	20.78	2,558	36.08
1990	1,329	8.67	7.17	6.59	22.44	2,830	59.22
1991	1,168	9.68	6.63	8.97	25.28	2,467	46.20

¹Includes exploratory and development wells; excludes service wells, stratigraphic tests, and core test.

Source: American Petroleum Institute.

TABLE 7
U.S. EXPORTS OF NATURAL BARIUM SULFATE (BARITE), BY COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Argentina	51	\$80	—	—
Barbados	1,373	166	338	\$38
Brazil	—	—	19,375	829
Canada	3,837	588	6,196	969
Colombia	27	13	4,044	300
Guinea-Bissau	447	135	—	—
Italy	7	18	—	—
Japan	71	18	324	51
Liberia	—	—	9	18
Mexico	3,180	392	3,535	492
Venezuela	6	11	9,469	602
Other ¹	228	254	6	5
Total	9,227	1,675	43,296	3,304

¹Includes the Dominican Republic, the Philippines, Saudi Arabia, and the Republic of South Africa.

Source: Bureau of the Census.

TABLE 8
U.S. BARITE MATERIALS IMPORT RATES OF DUTY

Tariff item	January 1, 1992				Non-MFN ³ January 1, 1992
	HTS No. ¹	General	Special	LDDC ²	
Barite other (crude)	2511.10.50	1.25 dollars per metric ton	Free (A, CA, E, IL)	Free	3.94 dollars per metric ton.
Barite, ground	2511.10.10	3.20 dollars per metric ton	Free (A, CA, E, IL)	Free	7.38 dollars per metric ton.
Barium carbonate	2836.60.00	0.9 cents per kilogram	Free (A, E, IL), 0.3 cents (CA) ad valorem	Free	3.3 cents per kilogram.
Barium chloride	2827.38.00	4.2% ad valorem	Free (A, E, IL) 1.6% (CA) ad valorem	Free	28.5% ad valorem.
Barium hydroxide, oxide and peroxide	2816.30.00	2% ad valorem	Free (A, E, IL), 0.8% (CA) ad valorem	Free	10.5% ad valorem.
Barium nitrate	2834.29.50	3.5% ad valorem	Free (A, E, IL) 1.4% (CA) ad valorem	Free	10% ad valorem.
Barium sulfate (blanc fixe/precipitated)	2833.27.00	0.4 cents per kilogram	Free (A, E, IL), 0.1 cents (CA) ad valorem	Free	2.8 cents per kilogram.
Witherite, crude ground	2511.20.00	3.0% ad valorem	Free (CA, E, IL)	Free	30% ad valorem.
Barium metal	2805.22.20	Free	Free	Free	25% ad valorem.

A-Generalized System of Preferences.

CA-U.S.-Canada Free-Trade Agreement.

E-Caribbean Basin Economic Recovery Act.

IL-United States-Israel Free-Trade Area.

¹Harmonized Tariff Schedule of the United States.

²Least developed developing countries.

³Most favored nation.

**TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF BARITE, BY COUNTRY**

Country	1990		1991	
	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)
Crude barite:				
Canada	488	\$52	1,006	\$99
China	849,963	35,131	710,760	31,445
India	101,649	3,552	123,400	3,798
Mexico	7,167	276	71	3
Peru	28,234	1,047	—	—
Other	42	45	5,705	538
Total²	987,543	40,103	840,942	35,883
Ground barite:				
Canada	9,293	2,693	10,986	2,830
China	3,000	398	—	—
Germany, Federal Republic of	94	45	178	90
Japan	270	218	172	175
Mexico	36,655	2,375	34,833	2,283
Morocco	7,165	357	—	—
Netherlands	247	108	94	43
Total²	56,7241	6,197	46,263	5,421

¹C.i.f. value.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

**TABLE 10
U.S. IMPORTS FOR CONSUMPTION OF BARIUM CHEMICALS**

Year	Blanc fixe (precipitated barium sulfate)		Barium chloride		Barium oxide, hydroxide, and peroxide	
	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)
1987	10,405	\$8,586	1,795	\$775	4,760	\$4,147
1988	23,326	8,754	4,188	834	8,558	4,109
1989	10,638	8,945	1,477	702	4,644	5,335
1990	10,354	8,675	1,510	783	4,186	5,275
1991	9,707	8,384	584	354	4,597	5,812
	Barium nitrate		Barium carbonate, precipitated		Other barium compounds	
	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)
1987	1,324	\$579	11,658	\$5,485	8,566	\$2,500
1988	2,754	567	19,209	4,803	2,165	3,439
1989	1,477	1,012	14,401	8,047	—	—
1990	1,178	1,394	11,201	6,038	—	—
1991	2,180	1,912	12,314	6,089	—	—

¹C.i.f. value.

Source: Bureau of the Census.

TABLE 11
U.S. IMPORTS FOR
CONSUMPTION OF WITHERITE¹

Year	Quantity (metric tons)	Value ² (thousands)
1987	396	\$144
1988	1,213	253
1989	76	30
1990	34	23
1991	18	8

¹Barium carbonate.

²C.i.f value.

Source: Bureau of the Census.

TABLE 12
WORLD BARITE ANNUAL
PRODUCTION CAPACITY,
DECEMBER 31, 1991

(Thousand metric tons)

Country	Rated capacity ¹
Algeria	109
Argentina	64
Australia	23
Belgium	41
Brazil	154
Canada	73
Chile	109
China	1,633
Czechoslovakia	64
France	154
Germany:	
Eastern states	36
Western states	204
India	590
Iran	181
Ireland	181
Italy	136
Japan	64
Korea, North	91
Malaysia	45
Mexico	544
Morocco	544
Pakistan	36
Peru	91
Poland	100
Romania	82
Thailand	181
Tunisia	23
Turkey	408
U.S.S.R.	544
United Kingdom	91
United States	1,451
Yugoslavia	45
Other ²	82
Total	8,174

¹Includes capacity at operating plants as well as at plants on standby basis.

²Includes Afghanistan, Austria, Bolivia, Burma, Colombia, Egypt, Finland, Greece, Guatemala, Kenya, the Republic of Korea, the Philippines, Portugal, the Republic of South Africa, Spain, and Zimbabwe.

TABLE 13
BARITE: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991 ³
Afghanistan ³	2,000	2,000	2,000	2,000	2,000
Algeria	⁴ 45,000	⁴ 43,000	⁴ 49,000	⁵ 53,078	53,000
Argentina	33,462	48,972	57,558	⁵ 50,000	50,000
Australia	10,363	10,970	¹ 10,000	¹ 11,000	11,000
Belgium ⁶	40,000	35,000	40,000	40,000	35,000
Bolivia	1,337	—	—	³ 300	⁴ 1,277
Brazil (beneficiated)	¹ 102,220	⁷ 78,842	51,407	⁵ 55,576	65,000
Burma ³	17,243	12,678	¹ 11,278	⁹ 9,145	9,000
Canada	42,000	51,000	39,000	48,000	45,000
Chile	52,109	43,135	59,873	³ 3,038	4,000
China ⁸	1,250,000	1,500,000	1,750,000	1,750,000	1,800,000
Colombia	³ 3,792	⁴ 4,550	5,460	⁵ 5,380	5,400
Czechoslovakia ⁶	60,000	⁶ 60,794	⁵ 50,800	⁸ 87,000	85,000
Egypt	4,116	5,651	7,295	⁶ 6,197	6,000
Finland	11,000	10,993	1,614	⁶ —	—
France	104,050	¹ 104,400	¹ 111,800	⁹ 92,500	90,000
Germany, Federal Republic of:					
Eastern states ⁶	32,000	32,000	30,000	² 25,000	NA
Western states	173,356	165,317	144,106	¹ 147,776	NA
Total ⁶	205,356	197,317	174,106	172,776	168,500
Greece ⁷	¹ 1,881	¹ 1,316	1,180	1,150	1,250
Guatemala	¹ 1,202	⁵ 5,064	3,995	⁴ 4,000	4,000
India	247,000	445,604	548,103	⁷ 707,000	500,000
Iran ³	⁴ 42,430	⁴ 44,309	⁵ 59,660	⁷ 77,423	75,000
Ireland	70,000	83,000	82,000	¹ 101,000	100,000
Italy	81,643	85,650	75,640	³ 36,500	49,000
Japan	31,625	—	—	—	—
Kenya	50	48	210	¹ 105	100
Korea, Republic of	2,942	2,573	3,735	² 2,923	3,000
Malaysia	38,935	38,766	36,526	⁴ 48,291	⁴ 16,600
Mexico	401,336	534,954	324,739	³ 304,996	² 210,664
Morocco	143,503	321,562	370,000	³ 363,580	360,000
Pakistan	10,031	22,198	29,718	² 23,329	23,000
Peru ⁶	⁸ 8,354	⁴ 40,000	⁴ 40,000	⁴ 40,000	45,000
Philippines	—	349	348	⁵ 500	500
Poland	73,100	63,100	⁵ 57,900	² 25,316	25,000
Portugal	660	1,740	1,729	¹ 1,220	1,400
Romania ⁶	⁴ 40,000	⁴ 40,000	⁴ 25,250	² 20,000	26,000
South Africa, Republic of	8,617	8,735	8,570	2,490	⁴ 4,790
Spain	33,761	6,585	⁶ 6,745	⁷ 7,000	6,000
Thailand	33,370	40,587	76,422	¹ 107,707	100,000
Tunisia	14,412	18,868	33,104	³ 30,885	30,000
Turkey	291,913	405,017	434,664	² 271,300	275,000
U.S.S.R. ⁶	540,000	540,000	540,000	500,000	450,000
United Kingdom	81,360	76,253	70,026	⁶ 67,551	65,000

See footnotes at end of table.

TABLE 13—Continued
BARITE: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991 ³
United States ⁴	406,000	404,000	290,000	439,000	⁴ 448,000
Yugoslavia	19,270	23,350	³ 30,509	² 23,601	20,000
Zimbabwe	191	3,400	1,900	¹ 1,800	1,800
Total	⁵ 4,607,634	⁵ 5,466,330	⁵ 5,573,864	⁵ 5,594,657	5,271,281

¹Estimated. ²Revised. NA Not available.

³Table includes data available through May 18, 1992.

⁴In addition to the countries listed, Bulgaria also produces barite, but available information is inadequate to make reliable estimates of output levels.

⁵Data are for fiscal year beginning Mar. 21 of that stated.

⁶Reported figure.

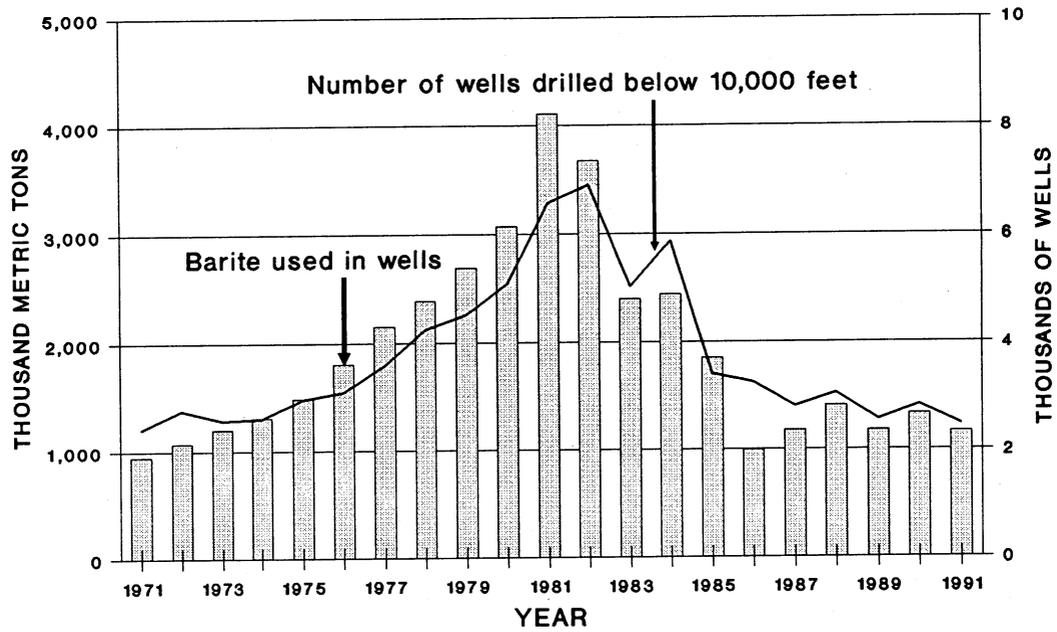
⁷Data are for fiscal year beginning Apr. 1 of that stated.

⁸Revised to zero.

⁹Barite concentrates.

¹⁰Sold or used by producers.

FIGURE 1
BARITE CONSUMPTION AND NUMBER OF OIL AND GAS WELLS DRILLED BELOW 10,000 FEET



^{1/}Excluding service, stratigraphic, and core tests.

BERYLLIUM

By Deborah A. Kramer

Ms. Kramer is a physical scientist with the Branch of Industrial Minerals. She has covered beryllium for 8 years. Domestic survey data were prepared by Shonta Osborne, statistical assistant; and the international data table was prepared by Ron Hatch, international data assistant.

Since its first commercial production in the United States in the early 1920's, beryllium has become an important material in many industrial and defense applications. Properties such as its high strength, light weight, and high thermal conductivity allow beryllium to be used for components in aircraft, satellites, electronic circuits, oil drilling equipment, and consumer goods.

The United States is the only market economy country with an integrated beryllium industry. Bertrandite, mined and processed in Utah, is the primary ore source for the end products—beryllium metal, beryllium alloys, and beryllium oxide—that are produced in Ohio and Pennsylvania. Imported beryl ore, mainly from Brazil, supplements domestic ore supply.

U.S. mine production continued to decline in 1991, a trend that began in 1988. Beryl imports continue to decrease, and the United States supplied a greater share of domestic demand. Brush Wellman Inc. was the sole U.S. beryllium mine producer with the capability to convert this ore and beryl into beryllium products.

Although the general economic downturn partially was responsible for a decline in U.S. beryllium consumption, not every end-use market was affected. A persistent decline in computer applications that began in 1989 resulted in weak demand for beryllium copper alloys, but a greater consumer demand for air-bag restraint systems led to an increase in beryllium-nickel consumption. Metallic beryllium consumption dropped because of a decrease in production of some defense components.

During 1991, however, manufacturers developed new products, such as beryllium-aluminum alloys that contain up to 40% beryllium, which were targeted toward the aerospace market. In addition, beryllium and beryllium-base alloys were used in new applications in the energy field, ranging from oilfield components to experimental fusion reactors.

DOMESTIC DATA COVERAGE

Beryllium data are collected from two voluntary surveys of U.S. operations. In 1990, there were eight responses to the "Beryllium Mineral Concentrate and Beryllium Ore" survey, representing 100% of the total canvassed. These respondents produced 100% of total domestic mine shipments, shown in tables 1 and 9. A small number of unidentified producers may have shipped insignificant quantities of byproduct beryl, which have not been included. (See table 1.)

BACKGROUND

Products for Trade and Industry

Beryllium-Copper Alloys.—Beryllium-copper alloys are used in a wide variety of applications and average about 65% of annual U.S. consumption on a beryllium metal equivalent basis. These alloys, most of which contain approximately 2% beryllium, are used because of their high electrical and thermal conductivity, high strength and hardness, good corrosion and fatigue resistance, and nonmagnetic properties. Beryllium-copper strip is manufactured into springs, connectors, and switches for use in applications in

automobiles, aerospace, radar and telecommunications, factory automation, computers, home appliances, and instrumentation and control systems. The principal use of large-diameter beryllium-copper tubing is in oil and gas drilling equipment and in bushings and bearings in aircraft landing gear and heavy machinery. Connectors in fiber-optic telecommunications systems are the main application for beryllium-copper rod. Small, pluggable sockets for joining integrated circuits to printed circuit boards are the main application for beryllium-copper wire. Beryllium-copper bar and plate are used in resistance-welding parts, components for machinery and materials-handling systems, and for molds to make metal, glass, and plastic components.

Beryllium also is used in small quantities in nickel- and aluminum-base alloys. Miniature electronic connector components that operate at high temperatures are the main use for beryllium-nickel alloys. Beryllium-aluminum alloys are used as castings in the aerospace industry. Addition of small quantities of beryllium to magnesium alloys inhibits oxidation.

Beryllium Metal.—Beryllium metal, which averages about 20% of annual U.S. demand, is used principally in aerospace and defense applications. Its high stiffness, light weight, and dimensional stability over a wide temperature range make it useful in satellite and space vehicle structures, inertial guidance systems, military aircraft brakes, and space optical system components. Because beryllium is transparent to X-rays, it is used in X-ray

windows. In nuclear reactors, beryllium also serves as a canning material, as a neutron moderator, in control rods, and as a reflector. In the past, the metal had been used as a triggering device in nuclear warheads. Other applications for metallic beryllium include high-speed computer components, audio components, and mirrors. In the U.S. space shuttles, several structural parts and brake components use beryllium.

Beryllium Oxide.—Beryllium oxide (beryllia) is an excellent heat conductor, with high hardness and strength. This material also acts as an electrical insulator in some applications. Beryllium oxide, averaging about 15% of domestic demand, serves mainly as a substrate for high-density electronic circuits for high-speed computers, automotive ignition systems, lasers, and radar electronic countermeasure systems. Because it is transparent to microwaves, microwave communications systems and microwave ovens may use beryllium oxide.

Industry Structure

The United States is the only country that can process beryllium ore and concentrates into beryllium products and supplies most of the rest of the world with these products. Brush Wellman mines bertrandite and converts this ore, along with beryl, to beryllium hydroxide at its facility in Delta, UT. Beryllium hydroxide is shipped to the company's plant in Elmore, OH, where it is converted into beryllium alloys and metal. Brush Wellman also produces beryllium oxide at a plant in Tucson, AZ, from the beryllium hydroxide recovered at Delta.

One other company in the United States has the capability to produce beryllium alloys. NGK Metals Corp., a subsidiary of NGK Insulators of Japan, produces beryllium alloys at a plant in Reading, PA. Because NGK Metals does not have facilities to process the raw materials, the company purchases imported beryl, and Brush Wellman converts the beryl into beryllium hydroxide under a tolling arrangement.

Ore production from labor-intensive operations outside the United States is sporadic, except for the largest producers—Brazil, China, and the U.S.S.R. Most of the beryl recovered in Brazil is exported to the United States, and that country is the largest U.S. beryl import source. Some beryl from China has been imported into the United States in the past, but it is assumed that China has some capability to process beryl because products, including beryllium-copper master alloy, originating there have appeared in the world market. Although little is known about the U.S.S.R., it is assumed that it has an integrated beryllium industry because little, if any, beryl produced in that country has been traded. With the separation of the U.S.S.R. into independent states, beryllium alloys, metal, and oxide have appeared on the world market. (See table 2.)

Geology

Because of its strategic importance, beryllium mineral occurrences in the United States were studied extensively in the years after World War II, particularly by the U.S. Geological Survey and the U.S. Bureau of Mines. During this period, the United States did not have a reliable domestic supply of beryllium minerals and was reliant on imports to supply most of its requirements. Most domestic beryllium was recovered from beryl produced as a byproduct of mining other pegmatite minerals. After production of bertrandite began in Utah in 1969, providing the United States with a secure beryllium source, little effort was made to evaluate additional beryllium mineral deposits.

Granitic pegmatites are the world's principal source of beryl. Beryl has been mined from zones, fracture-filling units, and replacement bodies in heterogeneous pegmatites. The principal beryl deposits are zones. Most beryl-rich zones contain only a few thousand metric tons of rock, but a few may contain as much as 1 million tons. Beryl occurs in concentrations of approximately 2% in zones containing plagioclase, quartz, and

muscovite mica, the principal product. It also is as abundant in zones from which spodumene, amblygonite, and feldspar are recovered.

Beryl tends to be finer grained in outer zones than in inner zones of pegmatites. Much of the fine- and medium-grained beryl of pegmatites in the Black Hills, SD, contains abundant inclusions of other minerals. Large masses of beryl containing almost no inclusions have been found in inner zones and may extend across several zones. Beryl is evenly distributed in some deposits, but in others it is irregularly distributed in rich aggregates in various parts of a zone.

None of the other beryllium minerals in pegmatites are of commercial importance. Chrysoberyl is concentrated in parts of some pegmatites but is much less abundant than beryl. Other beryllium minerals are exceedingly rare.

Beryl has been found in quartz veins containing cassiterite, wolframite, molybdenite, and other minerals. The concentration of beryl in the outer parts of these veins, just as beryl is concentrated in the outer part of quartz zones in some pegmatites, suggests that these quartz veins are genetically similar to pegmatites. Beryl crystals in quartz veins are normally less than 1 inch long. Beryl has been studied in the tin veins in South Dakota, England, and elsewhere. Beryl also has been reported in a tungsten vein in New Mexico and in quartz veins in Colorado; however, the mineral has not been reported in the more important tin and tungsten deposits of the world.

Replacement deposits that contain beryllium are primarily tactites and emerald-bearing schists. Helvite is the chief beryllium mineral of tactites and related rocks, but idocrase, grossularite, chlorite, and possibly other minerals also contain beryllium. The most thoroughly documented beryllium deposits in tactites in the United States are in New Mexico and Alaska, although the Alaskan deposits are of minor significance.

Nepheline syenite and other nepheline rocks have been reported to contain as much as 0.1% beryllium oxide. Deposits of this type have not been studied thoroughly enough to determine the

commercial feasibility of their development, although small quantities of beryllium-rich deposits have been found in Arkansas and Colorado.

Beryllium also has been found in coals. Sampling of a variety of U.S. coal ashes indicated a significant distribution pattern for beryllium, with an average of 46 parts per million for all of the samples. Accumulation of beryllium in coal was determined to be a syngenetic process, and the beryllium content of the coal primarily is dependent on the rocks that contributed material to the coal-depositional sites.

Technology

Exploration.—In many cases, the presence of beryl is visible by the naked eye. It appears as greenish-white crystals, and because it is usually associated with colorless quartz, large crystals are easily distinguished. For other beryllium minerals and finely disseminated beryl crystals, a beryllometer is normally used in the field for detecting beryllium mineralization. The beryllometer uses a gamma radiation supplied by an antimony 124 radioisotope to generate neutrons when the radiation field comes into contact with a beryllium-bearing mineral. This equipment is similar to a Geiger counter used to detect uranium. Beryllometers can be made with a sensitivity of 0.01% beryllium or less. Detection of beryllium in ore is usually followed by diamond drilling and assaying to delineate beryllium deposits further.

Mining.—Most of the beryl produced outside the United States is from Brazil, where labor-intensive, pick-and-shovel mining of weathered pegmatites is the primary method used. Garimpeiros (laborers) perform all of the mining and cobbing of the ore. Because the garimpeiros mine on private land and sell directly to ore buyers, information concerning mining methods and production is scarce.

Pegmatite mining in Brazil essentially consists of stoping into exposed, weathered pegmatites with picks and

shovels. Mines are established wherever beryl-rich pegmatites exist. Each stope is worked by three to five men who pick beryl crystals out of the host rock and muck out the waste. Other garimpeiros (usually women and children) sort through the mucked-out material for beryl crystals that were overlooked. Stopes are approximately 1.5 meters high and 1 meter wide. A mine can contain as many as 40 stopes.¹

In Utah, Brush Wellman mines bertrandite by open pit methods. Unlike beryl, in which the mineral can be identified by color and crystal structure, bertrandite mineralization cannot be recognized by the naked eye. Consequently, Brush Wellman conducts geologic and geochemical evaluations on a specific area, followed by a drilling program to determine if an economic ore body exists.

After delineating an ore body, overburden is removed to within 2 meters of the ore by a local earth-moving contractor during the winter and spring. This stripping operation usually requires about 9 months for completion. In the 2-meter cover remaining, drill benches are constructed on 7.5-meter centers to take samples of the ore body at 0.6-meter intervals. Information obtained from analyzing the samples allows cross-sectional and contour maps to be developed. These maps are used to plan the mining and processing operations.

After the maps are prepared, the remainder of the overburden is removed, and the ore is mined, typically with a self-loading scraper. Because of the irregular ore-grade distribution in the ground, the ore is mined from predetermined areas and placed in a stockpile in layers to obtain a homogeneous blend. Drilling, sampling, and assaying the stockpiled ore generate a map that identifies ore-grade distribution throughout the stockpile. Stockpiled ore is trucked to the mill, which is about 80 kilometers away, for further processing.

Beryllium Hydroxide Production.—Beryllium is recovered commercially from two ores—beryl and

bertrandite. Beryllium hydroxide, the intermediate product recovered from these ores, is subsequently converted to beryllium metal, alloys, or oxide. Brush Wellman is the only company with facilities to extract the beryllium values from both ores. Because of the difference in beryllium content of beryl and bertrandite, the ores are treated separately until the beryllium is dissolved, then the two solutions are combined.

Bertrandite is crushed and wet-milled to yield a slurry at about -20 mesh. The slurry then is leached with a sulfuric acid solution at about 95° C to dissolve the beryllium, forming a beryllium sulfate solution. In contrast, after crushing, beryl ore is heated to 1,700° C and quenched rapidly in water to form a frit. Heat treating the frit at 1,000° C, grinding to about -200 mesh, and then leaching with a concentrated sulfuric acid solution at 250° C to 300° C dissolves the contained beryllium, forming a beryllium sulfate solution.

After separating the solids from both beryllium sulfate solutions, the two solutions are combined. Solvent extraction is used to remove additional impurity elements that were extracted with the beryllium. In solvent extraction, the beryllium sulfate solution contacts an organic solution of di-2-ethylhexylphosphoric acid in kerosene. Beryllium is selectively dissolved in the organic solution. The slow rate of extraction at room temperature is accelerated by warming the extractant and leach solution. The loaded organic phase is treated with an aqueous ammonium carbonate solution, and beryllium is stripped from the organic phase forming $(\text{NH}_4)_2\text{Be}(\text{CO}_3)_2$.

In addition to beryllium, the solvent extraction step dissolves iron, aluminum, and fluoride. Heating the strip solution to about 70° C separates the iron and aluminum as hydroxide or carbonate precipitates. Two hydrolysis steps at 95° C and 165° C, respectively, remove the ammonia and carbon dioxide, resulting in the formation of beryllium hydroxide, which is filtered and then drummed for shipment. Approximately 80% of the

beryllium content of both the beryl and bertrandite is recovered by this process.²

Beryllium-Copper Alloy Production.—To produce beryllium-copper master alloy, beryllium hydroxide, electrolytic copper, and carbon are combined in an electric arc furnace. The resultant melt, containing about 4% beryllium, is cast into ingots. Remelting master alloy ingots with additional copper and other alloying elements yields the desired beryllium-copper alloy, which is then cast into slabs or billets. Slabs of beryllium-copper alloys are processed further into strip or plate, and billets are extruded into tube, rod, bar, and wire products.

Beryllium Metal Production.—To produce beryllium metal, beryllium hydroxide is dissolved in an ammonium bifluoride solution. Filtering and treating the solution with ammonium sulfide removes impurities such as iron, lead, manganese, and zinc. The purified solution is concentrated in an evaporator to yield an ammonium beryllium fluoride salt. After the salt is removed with a centrifuge and dried, it is fed to a continuous induction furnace. Decomposing the salt at 700° C to 900° C in the induction furnace produces molten anhydrous beryllium fluoride and ammonium fluoride gas, which is captured in scrubbers for reuse. Cooled beryllium fluoride is reacted with magnesium in batch induction furnaces to produce metallic beryllium and magnesium fluoride. Cooling the mixture produces a solid cake that contains beryllium pebbles, magnesium fluoride, and unreacted beryllium fluoride. Crushing this mixture followed by water leaching yields beryllium metal and magnesium fluoride. After separating the magnesium fluoride, the pebbles are vacuum melted to remove any slag trapped in them and cast into ingots.

Vacuum-cast ingots are normally further processed into a powder, produced by machining the ingot into chips. Chips cut by the lathe are removed by a vacuum system, and after passing through a cyclone, are automatically loaded into drums.

Grinding in a ball mill, impact grinding, or attrition grinding reduces the size of the chips. Each of these methods produces a different particle-size powder. In attrition grinding, chips are ground into a powder between a fixed, grooved beryllium plate and a rotating, grooved beryllium plate. In impact grinding, a high-velocity stream of air blasts a mixture of chips and oversize powder onto a solid beryllium target. Upon impact, the chips break into small particles that are removed from the chamber by vacuum conveying. A ball mill is used when extremely fine powder is required. After grinding, the beryllium powder is sized, either with screens or an air classifier. Beryllium powder is formed into billets by vacuum hot-pressing, hot-isostatic pressing, or cold-isostatic pressing, depending on the end use of the material.

Beryllium Oxide Production.—Beryllium oxide powder is produced by dissolving beryllium hydroxide in sulfuric acid. The resulting beryllium sulfate solution is concentrated by evaporation and cooled until the solution is supersaturated. During cooling, beryllium sulfate tetrahydrate crystals are produced. Wet salt crystals are removed from the mother liquor in a centrifuge. Calcining these crystals in a car-hearth furnace at temperatures up to 1,430° C decomposes the salt to beryllium oxide, water vapor, and SO₂ and SO₃ gases. The gases are fed through scrubbers, and the beryllium oxide is cooled, screened, and bagged for shipment.

Substitutes

Because of its high cost compared to those of other materials, beryllium is used in applications in which its properties are crucial. Steel, titanium, or graphite composites substitute for beryllium metal in some applications, and phosphor bronze substitutes for beryllium-copper alloys, but these substitutions result in substantial loss in performance. In some cases, aluminum nitride may be substituted for beryllium oxide.

Operating Factors

Beryllium dust and fumes have been recognized as the cause of beryllosis, a serious chronic lung disease. In the 1940's, the disease was diagnosed among industry employees and their relatives, who had handled dusty workclothes prior to the establishment of suitable hygienic procedures. Cases were also reported among residents of communities surrounding beryllium-processing plants. Although uncertainties related to the cause of the disease still exist, the problem appears to be controlled when established preventative measures are exercised. In beryllium-processing plants, harmful effects are prevented by maintaining clean workplaces; requiring the use of safety equipment such as personal respirators; collection of dust, fumes, and mists at the source of deposition in dust collectors; medical programs; and other procedures to provide safe working conditions. Control of potential health hazards adds significantly to the final cost of beryllium products.

Under the Clean Air Act, the Environmental Protection Agency (EPA) has issued standards for certain hazardous air pollutants, including beryllium. Beryllium emissions for plants that process beryllium materials are limited to 10 grams of beryllium over a 24-hour period. EPA also established water quality criteria for beryllium under the Clean Water Act. The Clean Water Act is intended to ensure a water quality sufficient to protect a use for which the water body has been designated. Typical designations include protection of aquatic life and wildlife habitat and protection of human health. A concentration level of 130 micrograms per liter of beryllium was established to protect aquatic organisms from acute health effects, and a level of 5.3 micrograms per liter was established for protection of chronic health effects. For human health, EPA established a concentration of 3.7 nanograms per liter to protect human health during the ingestion of water and fish, and a concentration of 64.1 nanograms per liter was established to

protect human health during the ingestion of fish only. Beryllium currently is not regulated by EPA under the Safe Drinking Water Act.

The Occupational Safety and Health Administration (OSHA) also issues standards for airborne beryllium particles. Current OSHA standards limit the 8-hour exposure level to an average of 2 micrograms per cubic meter, with a peak of 25 micrograms per cubic meter not to exceed 30 minutes, and a ceiling concentration of 5 micrograms per cubic meter. Mine Safety and Health Administration regulations affect only Brush Wellman's operation in Utah and are the same standards as those of OSHA.

ANNUAL REVIEW

Legislation and Government Programs

The Defense Logistics Agency extended its contract with Brush Wellman to convert beryl ore in the National Defense Stockpile (NDS) to vacuum-hot-pressed beryllium billets. The extension called for an additional 19,500 kilograms of beryllium, worth about \$13 million, to be delivered to the NDS in 1993. The contract was originally awarded in 1990, and this extension brings the total quantity of billet to 60,782 kilograms over a 3-year period. Some of the ore has been delivered to Brush Wellman in Utah for conversion to metal, but the NDS retains title to the material until the metal is delivered to the NDS. Because of this, the official yearend 1991 inventories in the NDS, shown in table 3, did not change from those at yearend 1990.

EPA reportedly planned to set Federal water-quality standards for 22 States that have not set their own standards. Under the 1987 amendments to the Clean Water Act, the 50 States and 5 territories were required to adopt specific water-quality standards for priority toxic pollutants, including beryllium, by February 4, 1990. Only 31 States complied with these amendments, which prompted EPA to announce its intent to impose Federal standards. (See table 3.)

Production

U.S. mine production of bertrandite declined in 1991, and inventories were drawn down slightly to meet world demand for beryllium products. Production of beryllium-copper master alloy, beryllium oxide, and beryllium-aluminum alloys dropped significantly in 1991. Production of metallic beryllium declined slightly. The only products that registered an increase in production were beryllium-nickel alloys, for which production nearly doubled from that of 1990.

Brush Wellman was the only integrated producer of beryllium in the United States. The company mined bertrandite at its open pit near Delta, UT, and processed this ore, imported beryl, and small quantities of domestically produced byproduct beryl into beryllium hydroxide at its facility in Delta. Beryllium hydroxide was shipped to Brush Wellman's plant in Elmore, OH, where it was manufactured into beryllium metal, beryllium alloys, and beryllium oxide. NGK Metals also produced beryllium alloys at its plant in Reading, PA, from beryllium hydroxide supplied by Brush Wellman.

Consumption and Uses

The general U.S. economic slowdown affected consumption for all beryllium products, continuing the drop in demand that began in 1988. In particular, a decline in demand was affected by a prolonged recession in the computer and electronic equipment markets, the principal end-use market for beryllium-copper alloys. Reduced demand for strategic defense systems because of recent world events primarily were responsible for the drop in beryllium metal consumption.

The Defense Reutilization and Marketing Service (DRMS) continued to be a source of beryllium scrap. Almost 3,800 kilograms of beryllium aircraft brake disks and assemblies was sold during 1991 at prices between \$25 and \$40 per kilogram. Brush Wellman was the principal purchaser of these materials.

DRMS also sold small quantities of beryllium-copper alloys and beryllium oxide.

In a bulletin issued on March 12, the U.S. Department of Defense clarified its position on the use of beryllium oxide ceramic materials in new applications. The bulletin stated that health hazards occur only from fine airborne particles that are encountered in the manufacturing process and not during the use of a finished device. Defense recognized that beryllium oxide was a safe product when handled in a solid form. In 1989, Defense had curtailed the usage of beryllium oxide because of perceived health hazards.³

Markets and Prices

Yearend prices for beryllium products are shown in table 4. Because of the economic conditions in 1991, prices for most beryllium products remained stable throughout the year, with the exception of beryllium metal. Powder and vacuum-cast lump prices rose about 4% and 37%, respectively. (See table 4.)

Foreign Trade

The Bureau of the Census does not separately identify all imports and exports of beryllium-copper alloys. The Journal of Commerce Port Import/Export Reporting Service (PIERS) provides some data on materials that are transported by ship. According to PIERS, 116,995 kilograms (gross weight) of beryllium-copper alloys in the forms of ingot, rod, and strip was exported. Japan was the destination for 79% of these exports, with the Federal Republic of Germany as the second largest recipient with 8% of the total. A small quantity of beryllium-copper master alloy was exported to Brazil.

PIERS reported that 177,234 kilograms (gross weight) of beryllium-copper alloys was imported in 1991. Sources of these imports were Japan, 69%; France, 18%; the Netherlands, 8%; and the United Kingdom, 5%. A total of 30,642 kilograms (gross weight) of beryllium-copper alloy scrap was imported from the

United Kingdom (62%) and Japan (38%).
(See tables 5, 6, 7, and 8.)

World Review

India.—According to Indian officials, a pilot plant for the production of beryllium metal was set up at the Bhabha Atomic Research Centre in Turbhe, New Bombay. The plant was designed to produce up to 2 kilograms per batch of beryllium for eventual conversion to vacuum hot-pressed beryllium metal and beryllium-copper alloy ingots. Both of these metals were expected to be used by India's Department of Space and Department of Atomic Energy.

Japan.—Demand for beryllium-copper alloys in Japan was estimated to have been reduced to 1,400 metric tons, a 10% decrease from the 1990 level. Most of the drop in demand occurred at the end of 1991 as a result of a recession in the Japanese economy. The principal end use for beryllium-copper alloys in Japan was in electrical and electronic components for motor vehicles and electronically controlled machine tools.⁴
(See table 9.)

OUTLOOK

Demand for beryllium-copper alloys should continue to be affected mainly by changes in the U.S. economy. Because these alloys are used in diverse applications, a downturn in only one or two end-use sectors is unlikely to have a significant effect on U.S. consumption. A prolonged recession, however, will continue to depress beryllium-copper alloy demand. The use of beryllium-nickel alloys should continue to grow. The predominant use of beryllium-nickel alloys is in automobile airbag systems, and more and more consumers are demanding these passive restraint systems in their new automobiles.

Metallic beryllium usage is unlikely to increase significantly. Beryllium's principal use is in defense applications, and because of decreased funding for some defense programs, production of new defense systems has been cut back.

Manufacturers are attempting to increase usage of beryllium components in other applications by developing new beryllium production methods to reduce the overall cost of the material. In addition, the manufacturers also are developing new families of intermetallic beryllium compounds, metal-matrix composites, and aluminum alloys that contain up to 40% beryllium. If these materials prove successful, new nondefense applications for beryllium may open up in the future.

The supply of beryllium ores could change drastically in the next few years. It is believed that the former U.S.S.R. has significant beryllium ore production capabilities and that much of the ore production was converted into beryllium metal and used within the country for military applications. With the recent changes in the former U.S.S.R. and that country's need for hard currency, it is likely that some of the beryllium ore will appear on the open market. With a reduction in the need for metals for its defense industry, beryllium metal produced in the former U.S.S.R. also may appear on the world market. (See table 10.)

¹Soja, A. A., and A. E. Sabin. Beryllium Availability—Market Economy Countries. BuMines IC 9100, 1983, 19 pp.

²Walsh, K. A. Extraction. Ch. in Beryllium Science and Technology, ed. by D. R. Floyd and J. N. Lowe. Plenum Press, v. 2, 1979, pp. 1-11.

³Lasers & Optronics. V. 10, No. 6, June 1991, p. 27.

⁴Roskill's Letter From Japan. No. 188, Dec. 1991, p. 2.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Beryllium. Ch. in Mineral Commodity Summaries, annual.

Other Sources

American Metal Market (daily paper).

Brush Wellman Inc., Annual Report.

Metals Week.

Roskill Information Services Ltd. Beryllium 1989, 5th ed.

TABLE 1
SALIENT BERYLLIUM MINERAL STATISTICS

(Metric tons of beryllium metal equivalent unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Beryllium-containing ores:					
Mine shipments	220	212	184	182	174
Imports for consumption, beryl ¹	83	35	24	14	12
Consumption, reported	323	243	217	232	196
Price, approximate, per short ton unit BeO, imported cobbed beryl at port of exportation	\$84	\$93	\$90	\$101	\$137
Yearend stocks	164	158	153	119	112
World: Production¹	345	332	301	*285	*264

¹Estimated. ²Revised.

¹Based on a beryllium metal equivalent of 4% in beryl.

TABLE 3
STOCKPILE STATUS,
DECEMBER 31, 1991

(Metric tons, beryllium content)

Material	Goal	Inventory
Beryllium-copper		
master alloy	287	268
Beryllium metal	363	290
Beryllium ore	653	¹ 653

¹Includes beryl held at Delta, UT, as part of the beryl upgrading contract.

TABLE 2
WORLD ANNUAL BERYL
PRODUCTION CAPACITY,¹
DECEMBER 31, 1991

(Metric tons, contained beryllium)

	Capacity
North America: United States²	360
Africa:	
Madagascar	5
Mozambique	3
Rwanda	3
South Africa, Republic of	3
Zimbabwe	5
Total	19
Asia: China	75
Europe:	
Portugal	3
U.S.S.R.	77
Total	80
South America:	
Argentina	4
Brazil	65
Total	69
World total	603

¹Includes capacity at operating plants as well as at plants on standby basis.

²Includes bertrandite ore.

TABLE 4
YEAREND BERYLLIUM PRICES

(Dollars per pound unless otherwise specified)

Material	Price
Beryl ore	per short ton unit of contained BeO \$78 - \$85
Beryllium vacuum-cast lump, 98.5% pure	308
Beryllium metal powder, in 1,000- to 4,999-pound lots and 98.5% pure	280
Beryllium-copper master alloy	per pound of contained Be 160
Beryllium-copper casting alloy	5.52 - 6.30
Beryllium-copper in rod, bar, wire	10.24
Beryllium-copper in strip	9.25
Beryllium-aluminum alloy, in 100,000-pound lots	260
Beryllium oxide powder	72.50

Sources: American Metal Market, Brush Wellman Inc., and Metals Week.

TABLE 5
U.S. EXPORTS OF BERYLLIUM ALLOYS,
WROUGHT OR UNWROUGHT, AND WASTE AND SCRAP,¹
BY COUNTRY

Country	1990		1991	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Angola	31	\$9	—	—
Australia	16	5	—	—
Brazil	51	9	40	\$4
Canada	29,557	859	11,846	297
France	810	430	279	309
Germany, Federal Republic of	1,624	1,220	7,284	488
Haiti	—	—	4,938	32
India	—	—	2,726	209
Ireland	—	—	11	3
Italy	33	4	—	—
Japan	475	180	1,075	598
Korea, Republic of	960	133	—	—
Mexico	439	40	1,057	30
Netherlands	1,968	228	663	244
Panama	—	—	2,623	7
Switzerland	354	114	227	163
Taiwan	28	12	5	23
United Kingdom	8,852	1,565	250	244
Other	29	23	98	39
Total	45,227	4,831	33,122	2,690

¹Consisting of beryllium lumps, single crystals, powder; beryllium-base alloy powder; and beryllium rods, sheets, and wire.

Source: Bureau of the Census.

TABLE 6
U.S. IMPORTS FOR CONSUMPTION OF BERYL, BY COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Brazil	342	\$418	252	\$347
Italy	—	—	36	47
Total	342	418	288	394

Source: Bureau of the Census.

TABLE 7
U.S. IMPORTS FOR CONSUMPTION OF BERYLLIUM METAL AND COMPOUNDS

Year	Beryllium-copper master alloy		Beryllium oxide and hydroxide		Beryllium, unwrought and waste and scrap	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
1990	99,614	\$871	589	\$28	10,982	\$132
1991	74,106	590	1,209	21	43,028	211

Source: Bureau of the Census.

TABLE 8
U.S. IMPORT DUTIES

Tariff item	HTS No.	Most favored nation (MFN)	Non-MFN
		Jan. 1, 1991	Jan. 1, 1991
Beryllium-copper master alloy	7405.00.6030	6.0% ad valorem	28.0% ad valorem.
Beryllium oxide or hydroxide	2825.90.1000	3.7% ad valorem	25.0% ad valorem.
Beryllium, unwrought	8112.11.6000	8.5% ad valorem	25.0% ad valorem.
Beryllium waste and scrap	8112.11.3000	Free	Free.
Beryllium, wrought	8112.19.0000	5.5% ad valorem	45.0% ad valorem.
Ore and concentrate	2617.90.0030	Free	Free.

TABLE 9
BERYL: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991 [*]
Argentina	46	39	89	*85	80
Brazil	1,000	913	800	*850	850
Madagascar ³	(⁴)	(⁴)	(⁴)	*3	*3
Nepal	(⁴)	(⁴)	1	*(⁴)	—
Portugal ⁵	4	4	4	4	4
South Africa, Republic of	(⁴)	(⁴)	—	*1	1
U.S.S.R. ⁶	2,000	2,000	2,000	1,600	1,300
United States ⁶ (mine shipments)	5,499	5,313	4,592	4,548	*4,339
Zimbabwe (concentrate, gross weight)	83	33	46	*28	30
Total	8,632	8,302	7,532	*7,119	6,607

^{*}Estimated. [†]Revised.

¹Table includes data available through Apr. 29, 1992.

²In addition to the countries listed, China produced beryl and Bolivia and Namibia may also have produced beryl, but available information is inadequate to formulate reliable estimates of production.

³Includes ornamental and industrial products.

⁴Less than 1/2 unit of measure; for Madagascar, production was, in kilograms: 1987—35; 1988—3; 1989—154; for Nepal, production for 1987 and 1988 was 10 kilograms and 400 kilograms, respectively; and for the Republic of South Africa, production for 1987 and 1988 was 135 kilograms and 72 kilograms, respectively.

⁵Revised to zero.

⁶Includes bertrandite ore, calculated as equivalent to beryl containing 11% BeO.

⁷Reported.

TABLE 10
BERYLLIUM SUPPLY-DEMAND RELATIONSHIPS

(Metric tons of beryllium content)¹

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
WORLD PRODUCTION											
Mine production:											
United States	266	197	242	219	209	237	220	212	184	182	174
Rest of world	119	121	119	141	117	119	125	120	117	*103	*90
Total	385	318	361	360	326	356	345	332	301	*285	*264
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mines	266	197	242	219	209	237	220	212	184	182	174
Shipments of Government stockpile excesses	—	—	—	—	—	—	—	—	—	—	—
Imports, metal	1	8	8	32	51	19	50	12	14	11	43
Imports, beryl	78	96	80	48	60	54	83	35	24	14	12
Industry stocks, Jan. 1 ²	49	81	185	255	205	181	177	164	158	153	119
Total U.S. supply	394	382	515	554	525	491	530	423	380	360	348
Distribution of U.S. supply:											
Industry stocks, Dec. 31 ²	81	185	255	205	181	177	164	158	153	119	112
Exports, metal and alloy	35	61	17	18	54	36	77	37	34	45	33
Government accessions	—	—	—	28	27	—	—	—	6	21	—
Industrial demand	278	136	243	303	263	278	289	228	187	175	203
U.S. DEMAND PATTERN											
Nuclear reactors	54	29	52	73	65	45	41	18	10	5	2
Aerospace	51	25	46	46	39	41	44	51	44	46	49
Electrical	101	49	87	105	91	108	109	66	36	35	32
Electronic components	46	24	41	53	46	62	68	80	88	79	99
Other	26	9	17	26	22	22	27	13	9	10	21
Total U.S. demand	278	136	243	303	263	278	289	228	187	175	203

*Estimated. †Revised.

¹Beryllium content of material classified as ore is considered to be 4%.

²Beryl ore.

BISMUTH

By Stephen M. Jasinski

Mr. Jasinski, a physical scientist with 5 years of U.S. Bureau of Mines experience, has been the commodity specialist for bismuth since 1988. Domestic survey data were prepared by Carolyn Crews, mineral data assistant. International Data were prepared by Harold Willis, international data assistant.

Increased production of bismuth chemicals boosted domestic consumption of bismuth 12% over that of 1990, according to the U.S. Bureau of Mines. Fusible alloy consumption also increased, but metallurgical additive uses dropped slightly. Consumers relied more on existing stocks of bismuth and less on imports, as shipments of bismuth to the United States declined from those of 1990.

Bismuth has become a leading candidate for replacing lead in many metallurgical and pigment applications. In 1991, it was announced that a bismuth-containing brass had been developed to replace leaded brass in some plumbing fixtures. Bismuth has also been tested as a replacement for steel shot in shotgun shells used in hunting waterfowl. Steel shot is currently used as a substitute for lead shot, but bismuth performs similarly to lead and is nontoxic.

Other recent developments include nontoxic ceramic glazes, bismuth-containing lubricating greases, and pharmaceuticals.

ANNUAL REVIEW

Legislation and Government Programs

The Defense Logistics Agency (DLA) which maintains the National Defense Stockpile (NDS), sold 56,880 kilograms of bismuth from the NDS in 1991. The Department of Defense proposed revising the goal for bismuth and other metals in the NDS. In its Annual Materials Plan, the Department of Defense has proposed reducing the goal for bismuth from 480,808 kilograms to zero.¹

The rate of disposal for fiscal years 1992 and 1993 will be 90,718 kilograms; the same amount is to be disposed of annually until the supply is exhausted. The inventory on December 31, 1991, was 828,280 kilograms.

Production

ASARCO Incorporated was the only domestic producer of primary bismuth. Production of bismuth at the company's Omaha, NE, refinery decreased slightly in 1991. To avoid disclosing company proprietary information, the data are not published. Several firms produced small quantities of secondary bismuth, mainly from fusible alloy scrap, but data on the quantities produced are not available.

Consumption and Uses

Domestic consumption of bismuth increased 12% over that of 1990. The largest increase was for bismuth chemicals mainly for industrial chemicals and pigments. The other chemical categories, pharmaceutical uses and cosmetic pigments, also grew in usage. Metallurgical additive use dipped slightly in the aluminum and steel industries.

Markets and Prices

The domestic dealer price was about \$3.00 per pound throughout the year, ranging from a brief low of \$2.70 in January to a high of \$3.25 per pound in July. The steady price was attributed to an adequate supply of bismuth and fairly level demand throughout the year.

Foreign Trade

Imports for consumption of bismuth metal were down 12% from those of 1990. The main sources were Mexico, Belgium, Peru, and China. Compared to those of 1990, imports from Belgium dropped almost 50% and imports from Peru, 35%. These decreases were offset partly by increased imports from Mexico and China. Exports were down 39% from those of 1990 owing to less bismuth-containing material being shipped to the United Kingdom for reprocessing.

World Review

Although world production of bismuth in 1991 was about the same as that in 1990, several companies stopped producing bismuth in 1991. RTZ Ltd. closed its Capper Pass tin smelter in the United Kingdom. The facility also produced bismuth and other minor metals. The closure was blamed on two major economic reasons, higher exchanges rates for the pound sterling, which increased toll refining charges, and a shortage of tin concentrates caused by low tin prices. The smelter has an annual production capacity of 4 metric tons of bismuth.

Capacity.—The data in table 5 are the rated annual capacity for mines and refineries as of December 31, 1991. Rated capacity is defined as the maximum quantity of material that can be produced in a given period of time on a normally sustainable long-term operating rate. It is based on the physical equipment of the plant and given acceptable routine

operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period with minimum capital expenditure.

Mine and refinery capacities for bismuth are based on combination of data on engineering capacity provided by some companies and estimates by the U.S. Bureau of Mines.

Bolivia.—Hexagon Resources, Flagstaff, AZ, began negotiations with Corporacion Minera de Bolivia (COMIBOL), the state-run mining company, to produce bismuth at the Tasna Mine. Bolivia is the only country where bismuth has been mined as a primary product on a large scale. COMIBOL closed Tasna in 1979 because of mounting losses. It was reopened briefly in 1985, but declining bismuth prices have kept it closed since then.

Canada.—Brunswick Mining and Smelting Co., Ltd., a subsidiary of Noranda Minerals Inc., produced about 100 tons of bismuth contained in bismuth-lead alloys, averaging 6% bismuth. This was down from that of previous years owing to a strike by the smelter employees that was not settled until May. The alloys were shipped to Belgium and the U.S.S.R. for refining; however, with the dissolution of the U.S.S.R., the company has had trouble finding a steady buyer for their product. Bismuth production will remain small, unless there is an increase in demand.

Cominco Ltd. recovered bismuth sporadically in 1991 as a byproduct of its lead refining circuit. Total output was about 100 tons. Cominco and Noranda have both resigned as sponsoring members of the International Bismuth Institute because of each company's reduced output and sales of bismuth.

France.—Les Mines de Salsigne, which recovered bismuth as a byproduct of gold production, ceased operations because of mounting losses. The mine produced

about 60 to 80 tons of crude bismuth annually, which was sent to Sidech in Belgium for refining.

Korea, Republic of.—Korea Tungsten Mining Co. suspended production of bismuth in the second half of the year. Bismuth was recovered as a byproduct of tungsten, but dwindling reserves and the depressed price of tungsten forced the company to stop production. Korea Tungsten has an annual production capacity of 200 tons per year, but production has been less than 100 tons for the past 3 years, most of which was exported to Japan.

Current Research

The application of bismuth as a nontoxic substitute for lead in a variety of uses dominated research news on bismuth in 1991. The most prominent announcement came from AT & T Bell Laboratories, which announced the development of a lead-free brass for use in plumbing fixtures. Lead is usually added to the brass to allow it to be machined easily, as it provides lubrication and allows the chips of metal to break off readily. Increased concerns about lead possibly leaching into drinking water from faucets and pending legislation to ban lead in many applications prompted research in this area. The only drawback to using bismuth was its brittleness, but this was alleviated by adding a small amount of either tin or phosphorus, which gave the brass nearly the same characteristics as leaded brass.

Actual widespread substitution is highly unlikely because the world supply of bismuth is limited. World production is about 4,000 tons per year and annual refinery capacity is more than 8,000 tons, but it would require at least 5 to 10 years for new mines and refineries to begin production. An increase of 2,000 tons in 2 to 3 years seems to be achievable. Bismuth is also much more expensive than lead, and new products would reflect this increase. Nibco Inc., Elkhart, IN, has begun production of a full line of lead-free plumbing fixtures, marketed for use in new homes only.²

There is also a problem with mixing bismuth brass scrap with lead brass scrap. Bismuth is considered a contaminant in brass mills, and measures would have to be taken to prevent this from occurring.

Bismuth is being investigated as a replacement for steel shot in shotgun shells. Steel shot is used as a replacement for lead shot, which was used for hunting waterfowl. Lead was banned for use in shot because some birds were found to be suffering from lead poisoning from ingesting the shot that had accumulated in the wetlands. Steel has some disadvantages; first, it is much harder than lead and is much more detrimental to the gun barrel; second, the steel shot often passes through birds and just wounds them, whereas bismuth and lead deform slightly upon impact; third, steel shot is much lighter than lead, requiring a larger size pellet. As with the brass, issues of availability and price must be assessed before any action will take place. Bismuth shot has not been approved for use, but it is being tested by the Canadian Wildlife Service.³

Drakenfeld Colors has patented a new bismuth pigment that will be used as replacement for lead pigments in certain ceramic enamels. The pigment has shown the same degree of durability as the lead pigments; however, it is not compatible with certain cadmium-bearing yellow-orange and red pigments.⁴

American Superconductor Corp. has produced a bismuth-silver superconductor that can be drawn into flexible wire up to 40 meters in length. The total amounts of bismuth used in this and other superconductor uses has been very small and used for experimental purposes only.⁵

OUTLOOK

The future for bismuth is optimistic, evidenced by the increase in consumption and the variety of new applications that have been developed. The release of NDS bismuth and the resumption of production in Bolivia could help supply bismuth for some of the more promising new uses in the next 5 years. World production could also increase in other countries if economic conditions are

favorable. Bismuth has the advantage of being nontoxic, which is expected to keep demand rising gradually in the next decade.

¹U.S. Secretary of Defense. Report to Congress on National Defense Stockpile Requirements, 1992. Feb. 1992, 100 pp.

²Plewes, J. T., and D. Loiacono. Free-Cutting Copper Alloys Contain No Lead. Adv. Materials and Processes, Oct. 1991, pp. 23-27.

³Boddington, C. Breakthrough in Bismuth Shot. Peterson's Hunting, Jan. 1992, pp. 31-32, 80.

⁴Reinherz, B. Drakenfeld Introduces Lead-Free Enamels. Ceramic Ind. Dec. 1990, p. 43.

⁵Edelson, E. Superconductors Take Off. Popular Sci. v. 238, No. 5, May 1991, pp. 101-105.

TABLE 1
SALIENT BISMUTH STATISTICS

(Metric tons unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Consumption	1,597	1,531	1,352	1,274	1,427
Exports ¹	38	147	122	122	75
Imports for consumption	1,581	1,641	1,880	1,612	1,411
Price, average, domestic dealer, per pound	\$3.65	\$5.78	\$5.76	\$3.56	\$3.00
Stocks, December 31: Consumer	294	433	440	344	325
World:					
Mine production (metal content) ²	3,173	3,220	³ 3,649	³ 3,359	³ 3,301
Refinery production ²	4,078	⁴ 4,099	⁴ 4,194	⁴ 4,060	⁴ 4,038

³Estimated. ⁴Revised.

¹Includes bismuth, bismuth alloys, and waste and scrap.

²Excludes the United States.

TABLE 2
BISMUTH METAL CONSUMED IN THE UNITED STATES, BY USE

(Metric tons)

Use	1987	1988	1989	1990	1991
Chemicals ¹	748	679	659	577	789
Fusible alloys	334	332	272	249	271
Metallurgical additives	494	493	396	424	341
Other ²	21	27	25	24	26
Total	1,597	1,531	1,352	1,274	1,427

¹Includes industrial and laboratory chemicals, cosmetics, and pharmaceuticals.

²Includes other alloys and experimental uses.

TABLE 3
U.S. EXPORTS OF BISMUTH, BISMUTH ALLOYS, AND
WASTE AND SCRAP, BY COUNTRY

Country	1990		1991	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Belgium	—	—	4,434	\$535
Brazil	—	—	689	13
Canada	36,882	\$571	30,904	11
China	—	—	19,823	11
Egypt	—	—	154	4
France	425	4	—	—
Germany, Federal Republic of	158	19	—	—
Hong Kong	2,331	17	—	—
Ireland	449	8	—	—
Italy	1,706	32	—	—
Korea, Republic of	108	8	—	—
Malaysia	—	—	21	3
Mexico	117	9	—	—
Singapore	2,217	26	1,927	17
Taiwan	1,057	15	572	6
United Kingdom	76,227	169	16,073	41
Total	121,677	878	74,597	641

Source: Bureau of the Census.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF METALLIC BISMUTH, BY
COUNTRY

Country	1990		1991	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Belgium	668,071	\$5,111	345,078	\$2,132
Bolivia	—	—	60,239	363
Canada	130,071	723	48,660	319
China	54,229	382	104,721	617
Germany, Federal Republic of	17,260	207	40,463	97
Hong Kong	—	—	54,819	327
Japan	339	236	26	32
Mexico	404,821	2,471	534,966	2,687
Peru	262,705	2,095	169,778	1,014
Spain	—	—	11,965	57
United Kingdom	74,366	522	40,679	231
Total	1,611,862	11,747	1,411,394	7,876

Source: Bureau of the Census.

TABLE 5
ESTIMATED ANNUAL BISMUTH PRODUCTION CAPACITY,
DECEMBER 31, 1991

(Metric tons)

Country	Mine	Refinery
Australia	1,800	—
Belgium	—	1,100
Bolivia	700	300
Canada	700	300
China	1,500	1,500
Germany, Federal Republic of	—	400
Italy	—	100
Japan	700	1,200
Korea, Republic of	250	250
Mexico	1,100	1,000
Peru	900	800
Romania	100	100
U.S.S.R.	100	200
United Kingdom	—	400
United States	700	500
Yugoslavia	150	150
Total	8,700	8,300

TABLE 6
BISMUTH: WORLD MINE AND REFINERY PRODUCTION, BY COUNTRY¹

Country	Mine output, metal content					Refined metal				
	1987	1988	1989	1990	1991*	1987	1988	1989	1990	1991*
Australia*	350	400	500	400	400	—	—	—	—	—
Belgium*	—	—	—	—	—	865	1,000	800	800	750
Bolivia	1	13	41	'54	—	—	—	—	—	—
Canada ²	165	181	'157	'100	100	218	225	272	'280	270
China*	600	750	'850	'1,000	1,100	600	750	'850	'1,000	1,100
France*	90	90	100	'70	—	—	—	—	—	—
Germany, Federal Republic of:										
Western states	—	—	—	—	—	'300	—	—	—	—
Italy	—	—	—	—	—	43	32	'46	'34	35
Japan ³	'165	'160	'150	'133	135	546	524	502	'442	450
Korea, Republic of ²	'145	'132	'96	'79	80	145	132	96	'79	80
Mexico	1,012	958	883	'733	690	561	622	597	'549	500
Peru	412	363	687	'555	616	387	'341	'646	'521	578
Romania*	75	65	60	70	60	75	65	60	65	55
U.S.S.R.*	85	85	85	80	70	85	85	85	80	70
United Kingdom*	—	—	—	—	—	180	300	200	125	100
United States	W	W	W	W	W	W	W	W	W	W
Yugoslavia	73	23	40	'85	50	73	23	40	'85	50
Total	3,173	3,220	'3,649	'3,359	3,301	4,078	'4,099	'4,194	'4,060	4,038

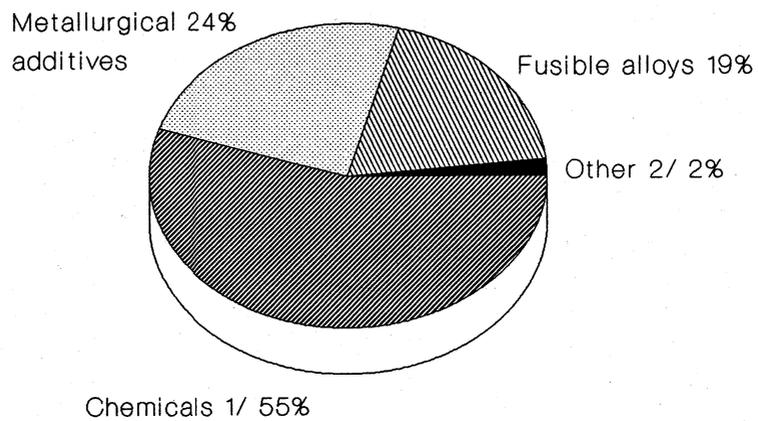
*Estimated. Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

¹Table includes data available through Apr. 2, 1992. Bismuth is produced primarily as a byproduct of other metals, mostly lead, and only in Bolivia is it mined for itself.

²Figures listed under mine output are reported in Canadian sources as production of refined metal and bullion plus recoverable bismuth content of exported concentrate.

³Mine output figures have been estimated based on reported metal output figures.

FIGURE 1
BISMUTH METAL CONSUMED IN THE UNITED STATES IN 1991



1/Includes industrial and laboratory chemicals, cosmetics, and pharmaceuticals.
2/Includes experimental and other alloys.

BORON

By Phyllis A. Lyday

Mrs. Lyday has covered boron for 13 years. Domestic survey data were prepared by Pam Shorter, statistical assistant; and international data were prepared by Harold Willis, international data coordinator.

U.S. production and sales of boron minerals and chemicals decreased during the year. Domestically, glass fiber insulation was the largest use for borates, followed by sales to textile-grade glass fibers, sales to distributors, and borosilicate glasses.

California was the only domestic source of boron minerals. The United States continued to provide essentially all of its own supply while maintaining a strong position as a source of sodium borate products and boric acid exported to foreign markets.

Supplementary U.S. imports of Turkish calcium borate and calcium-sodium borate ores, borax, and boric acid, primarily for various glass uses, continued.

DOMESTIC DATA COVERAGE

Domestic data for boron are developed by the U.S. Bureau of Mines from two separate, voluntary surveys of U.S. operations. Of the three operations to which a sold and used survey request was sent, three responded, representing 100% of the total boron sold or used shown in tables 1 and 10. A Bureau canvass of the three U.S. producers also collected data on domestic consumption of boron minerals and compounds shown in tables 4 and 5. (See table 1.)

BACKGROUND

Definitions, Grades, and Specifications

Few of the many minerals that contain boron are commercially valuable. Only colemanite and ulexite minerals, primarily imported from Turkey, are

marketed in the United States. The boron oxide content of both minerals is usually marketed at about 40%. (See table 2.)

Tincal and kernite ore and brines are the U.S. source of refined borate chemical compounds. The most common refined borates, borax pentahydrate and its derivative anhydrous borax, are marketed in technical and agricultural grades. Lesser quantities of borax decahydrate are produced in technical, United States Pharmacopeia and special quality grades.

Boric acid is a white, odorless, crystalline solid sold in technical national formulary and special quality grades as granules or powder. Boron oxide is a hard, brittle, colorless solid resembling glass that is ground and marketed most often under the name anhydrous boric acid.

Elemental boron is a dark brown powder in the amorphous form and a yellowish-brown, hard, brittle solid in the monoclinic crystalline form. Boron is marketed in grades from 90% to 99% purity.

Ferroboron is a name given to a variety of boron-iron alloys containing 0.2% to 24% boron used primarily to introduce small quantities of boron into specialty steels.

In the boron hydride series are diborane, a gas; pentaborane, a liquid; and decaborane, a solid. These compounds range from 31,220 British thermal units (Btu) per pound for diborane to 27,850 Btu per pound for decaborane. A history of the boron fuels project was told in a recent book. The book describes the pilot-plant production at the Malta Rocket Test Station.¹ Sodium borohydride is marketed in powder or

pellet form and in sodium hydroxide solution.

Boron nitride, a soft, white, highly refractory solid resembling graphite, can withstand significant oxidation to temperatures up to 650° C. Boron nitride produced in fibrous form equals glass fibers in strength and modules of elasticity, but is lighter in weight and more resistant to high temperature. When subjected to extremely high pressure and temperature, boron nitride forms cubic crystals that rival the harness of diamond.

Boron carbide, produced by reacting carbon and boric acid at 22,600° C, is a highly refractory material and one of the hardest substances known. Most commonly used for both abrasive and abrasion-resistant applications as well as nuclear shielding, boron carbide is marketed in technical and high-purity grades.

Byproducts and Coproducts

More than four-fifths of the U.S. production comes from mineral deposits mined only for their boron content. The remainder is produced from lake brines, which also supply sodium carbonate, sodium sulfate, potassium sulfate, and potassium chloride. Turkish colemanite, ulexite, and tincal ores are worked only for their boron content. Most Soviet borates are also mined only for their boron content, but the Gulf of Kara-Bagaz-Gol and the Sivash (lagoon) borates are extracted with coproduct chloromagnesium from brines. South American boron has been mined from ores and also has been produced as a coproduct of nitrate and iodine production.

Economic Factors

Costs.—Energy costs are especially high for producing anhydrous products. The anhydrous products were originally introduced to decrease freight costs per ton of contained boron oxide. Both domestic producers now use cogeneration facilities to reduce the cost of energy for processing and supplying excess electricity for sale. (See table 3.)

Depletion Provisions.—The domestic and foreign depletion allowances for boron are 14% of gross income and may not exceed 50% of net income without the depletion deduction.

Operating Factors

Naturally occurring boron compounds have relatively low toxicity for humans and other mammals. U.S. Borax & Chemical Corp. submitted a Toxic Substance Control Act Section 8(e) risk report (No. 2002) to the U.S. Environmental Protection Agency (EPA). Results of a teratology study of boric acid reported no observed adverse effects.²

Occupational Safety and Health Administration's (OSHA) Hazard Communication Standard went into effect November 1985 and May 1986. It is OSHA's most comprehensive worker protection regulation. It provides for information and training for workers encountering chemical exposures in the workplace. The standard requires the use of labels and material safety data sheets for all regulated chemicals. Part of the standard includes the Threshold Limit Values (TLV) from the American Conference of Governmental Industrial Hygienist. TLV's refer to airborne concentrations of substances and represent conditions under which nearly all workers might be repeatedly exposed day after day without adverse effect. The only hazard listed for boron chemicals produced at the mine site was a Time Weighted Average for borax decahydrate, listed as 5 milligrams per cubic meter per 8-hour workday, 40-hour workweek, to which nearly all workers may be repeatedly exposed without adverse

effect. Sodium borates, boric acid, and boron oxide are not present to any significant degree in air and are placed in the same hazard category as general dust.³

Small quantities of boron are essential for all plant life. Boron is added in trace levels to fertilizers; however, quantities well below concentrations affecting humans and animals are so extremely toxic to vegetation that boron compounds are also used commercially as herbicides. Concentrated boric acid is used to control certain insects and in dilute solutions as a preservative to control the growth of bacteria.

ANNUAL REVIEW

Legislation and Government Programs

Debate opened before the full House Interior Committee on the California Desert Protection Act. Under the proposed bill, 4.3 million acres of public land would be designated wilderness. In addition to the wilderness designation, the bill would add 1.3 million acres of Federal lands to the existing Death Valley National Monument and 200,000 acres to the Joshua Tree National Monument. The land under discussion contains numerous mineral deposits, including most known boron reserves. At yearend, H.R. 2929 had passed the House and was sent to the Senate for further consideration.

The Department of Commerce (DOC) published in the January 7, 1991, Federal Register that the DOC will soon publish a regulation amending the national security export controls on pyrolytic boron nitride (PBN). Initially, the Department intended to remove national security-based validated licensing requirements to all noncontrolled destinations. Following multilateral review by the Coordinating Committee for Multilateral Export Controls (COCOM), the Department published in the Federal Register on September 1 an announcement of the decontrol of PBN licensing requirements for exports to controlled countries.

Production

The majority of boron production continued to be from Kern County, with the balance from San Bernardino and Inyo Counties, CA.

American Borate Co. (ABC), a wholly owned subsidiary of Owens-Corning Fiberglass Corp., was sold in December of 1990 to a private firm. ABC renewed its mine permits and began to mine small amounts of colemanite and ulexite from the Billie Mine during 1991. Colemanite was processed at Lathrop Well, NV. Storage and grinding facilities were at Dunn, CA.

North American Chemical Co. operated the Trona and Westend plants at Searles Lake, in San Bernardino County, to produce refined sodium borate compounds and boric acid from the mineral-rich lake brines. At the Trona plant, a differential evaporative process produced borax with potash as a byproduct. Boric acid was produced by solvent extraction. The Westend plant continued production of sodium borates by a carbonation process. Brines used in the process were pumped to the Argus plant to produce sodium sulfate.

United States Borax & Chemical Corp., a part of Borax Consolidated Ltd. of the RTZ Corp. PLC of London, United Kingdom, continued to be the primary world supplier of sodium borates. RTZ is traded on the New York Stock Exchange.

U.S. Borax mined and processed crude and refined sodium borates, their anhydrous derivatives, and anhydrous boric acid at Boron, in Kern County, CA. A second plant at Boron used a proprietary process to produce technical-grade boric acid from U.S. Borax's extensive kernite ore reserves. The boric acid was produced to compete with imported colemanite used in glass manufacture.

The majority of material was shipped to U.S. Borax's storage, Wilmington, CA. Products made at Wilmington included ammonium borates, potassium borates, sodium metaborates, and zinc borate.

During 1991, experiments to grow natural-type plants on the mine wastes were begun. The experiments will

establish the proper slopes, vegetation, and methodology for reclaiming and resurfacing the mine waste.

During 1991, U.S. Borax, Boron, CA, received a runner-up award for the Sentinels award. To be eligible for the award, a mine must have accrued at least 30,000 injury-free hours. During 1991, all runners-up worked the entire calendar year without a lost-time injury.⁴

Consumption and Uses

U.S. consumption of borates decreased. Glass fiber insulation and glass fiber primarily used as reinforcement for plastics continued to be the largest consuming industries.

The use of borates in glass fiber thermal insulation, primarily used in new construction, was the largest area of demand for borates. Cellulosic insulation, the seventh largest area of demand, decreased.

The second major market for borates, manufacturing high-tensile-strength glass fiber materials for use in a range of products, showed an increase in demand. The nonconductive and low dielectric properties of high-strength glass-reinforced materials make them transparent to radar and thus valuable for "stealth" applications. Carbon-fiber-reinforced resins can be stronger than metals and, with higher modules, more stable. Although composites can be 10 times more expensive than typical aerospace-grade aluminum, the flexibility they offer in design and consolidation of parts allows large complex structures to be fabricated to exacting specifications. In addition, their light weight and ability to withstand high temperatures have made them the material of choice for a variety of aerospace applications.

A boron-reinforced epoxy patch was used to reinforce structural cracks in the B-1 bomber. The material was supplied by Textron Specialty Materials of Lowell, MS. The boron-epoxy patch technique was chosen after more traditional methods failed. The titanium longerons will be reinforced with two boron-epoxy patches that are about five times stronger and six times stiffer than aluminum

alloys. The patches must be applied in thinner layers, which is important for aerodynamic surfaces, to achieve the same amount of reinforcement.⁵

Consumption of borates in borosilicate glasses remained the third major end use, and demand decreased. Boron added in amounts of between 4% to 15% to glass reduced the viscosity of the melt, assisted with fiber formation during processing, and allowed for improved specific optical properties, increased resistance to aqueous or chemical attack, enhanced certain mechanical properties, and reduced the thermal expansion coefficient and thermal shock resistance of the product. Boron oxide provides a range of favorable benefits to the melting of nonspecialty and container glass and the final glass properties. Each 1% of boron oxides reduces the melting temperature of the glass 20° C.⁶

Boron compounds continued to find application in the manufacture of biological growth control chemicals for use in water treatment, algicide, fertilizers, herbicides, and insecticides. Boron can be applied as a spray and incorporated in herbicides, fertilizers, and irrigation water. The Potash & Phosphate Institute recommended one-half pound of boron for every ton of expected yield of alfalfa in the Spring 1992 Agri-Briefs. The brief recommended that micronutrient levels in the soil be monitored by soil testing.

A growing and important use of borax and boric acid was as a fire-retardant-treatment wood to be used as an alternative to noncombustible materials for building applications. Fire retardant chemicals reduce the rate at which flames travel across the wood surface, thereby reducing the capacity of the wood to contribute to a fire. The chemicals increase the amount of char and reduce the amount of flammable volatiles, but also lower the temperature at which thermal degradation occurs.⁷ The amount of degradation depends upon the chemical species present, elevated temperature levels, duration of exposure, and moisture content.⁸ Most fire retardant treatments significantly reduce the strength and stiffness of the treated wood product.⁹ ASTM is in the process of developing a

protocol for assessing impregnated chemical effects on long-term properties of wood products.¹⁰

Boron compounds were also used in metallurgical processes as fluxes, shielding slag in the nonferrous metallurgical industry, and components in electroplating baths. Small amounts of boron and ferroboration were constituents of certain nonferrous alloys and specialty steels, respectively.

Boron is also used as a bleaching agent in detergents and cleaning products, such as compact washing powders. Interlox America started up a plant in Texas for production of 45 million pounds per year of sodium perborate monohydrate. The other U.S. supplier is E.I. Du Pont de Nemours & Co. With the added capacity, imports will not be necessary to supply demand.¹¹ (See tables 4 and 5.)

Prices

Prices for anhydrous, pentahydrate, and decahydrate borax and technical boric acid decreased. Only the price for Turkish ulexite increased. (See table 6.)

Foreign Trade

The majority of material from the U.S. Borax facility in Boron was shipped to storage, loading, and shipping facilities at Wilmington, CA. A large part of the output was exported to Western Europe from Wilmington to Botlek, Netherlands. (See tables 7 and 8.)

World Review

Corning Inc. and Vitro, Sociedad Anonima, Mexico's largest glass manufacturer, have signed a letter of intent to create a new worldwide joint venture dedicated to consumer housewares. The alliance will combine annual sales in excess of \$800 million. Under the terms of the proposed transfer, Corning would transfer its worldwide consumer assets and business to a newly formed U.S. subsidiary called Corning Vitro Corp. Likewise, Vitro will form a Mexican subsidiary to be called Vitro Corning S.A. de C.V.¹²

Capacity.—The data in table 9 are rated capacity for mines and refineries as of December 31, 1991. Mine capacity for boron was based on rated capacity as reported by the company, by another government agency, or another published source. Capacity outside of the United States was limited by the availability of loading and transportation equipment and market demand, rather than limitations of ore grade. (See table 9.)

Argentina.—Boroquimica SA continued production of tincal and boric acid from a deposit at Tincalayu.

Bolivia.—Compania Minera Tierra Ltd., a small company formed in 1988 for producing borates in an area of the Department of Potosi, obtained a loan of \$1.6 million from the Inter-American Investment Corp. The firm has important concessions of ulexite and sulfur near the Chilean border in the southwestern tip of the country. About 120,000 tons of ulexite per year is exported to Brazil and other neighboring countries. In 1990, the company employed 120 persons.

The company has interest in ulexite mineral concessions at the following locations: Kapina, Chalviri, Pastos Grandes, Chiguana, Leguani, and Empexa. The concessions cover an area of 4,800 hectares, and reserves have been estimated by the company to exceed 13 million tons of raw ulexite with grades ranging from 20% to 37%.

Ulexite is extracted and dried by turning by tractor. The dried ulexite is washed and roasted. The processed ulexite of about 42% borate content is bagged and exported by trucks and rail.

The loan received will finance a boric acid plant at Apacheta, Department of Potosi. The plant is near the location of a geothermal field that plans electric generation beginning in 1993. The boric acid will be produced by combining ulexite with sulfur dioxide produced by burning sulfur.

A new compendium of information on the geology and mining in Bolivia was released at the National Western Mining Conference and Exhibit. The compendium was the result of studies

commissioned by the Ministry of Mining and Metallurgy under the direction of the Bolivian Geological Survey and funded by the U.S. Trade and Development Programs. The compendium contains details of more than 700 mines and mineral occurrences, including the geology and metallogenesis of each locality. A section on investment conditions and recent changes to the Bolivian Mining Law was also included.¹³

Chile.—Quiborax is the main producer of boric acid and concentrated ulexite. Minera del Boro, Minera Ascotan, and Boroquimica are smaller local producers. Quiborax and Minera del Boro planned capacity increases. By 1994, Minsal planned to have completed a boric acid expansion of 18,000 tons per year.

Compania Minera Salar de Atacama (Minsal), a joint-venture project between AMAX of the United States, Molibdenos Y Metales (Molymet) of Chile, and Corporacion de Fomento de la Produccion (CORFO). CORFO established the joint venture as a result of an international public licitation in 1986, in which the Lithium Corp. of America (LITHCO) was the only other bidder. The project was designed to produce lithium carbonate, potassium chloride, potassium sulfate, and boric acid from the Salar de Atacama in the Second Region. Future production was expected to be 26,000 tons of boric acid per year. In February 1991, the project was placed on hold for a second year, under the terms of AMAX's original contract.¹⁴

China.—The borates in the salt lakes of China are mainly found on the Qinghai-Xizang (Tibet) Plateau. Boron is distributed in many saline lakes from the southern side of the Gilian Mountains in the north side of the Gangdisi-Tanggula mountains. Most borates exist in the Holocene sediments, some in the late Pleistocene. Most are concentrated on the hot spring side of the lake basin. Borax and tincalconite are mainly found in the salt lakes of carbonate-type, and the pinnoite, kurnakovite, and other Mg-borates in the lakes of sulfate-type.

Investigations on the source of borate are as follows: Geothermal water and acid magmatic rock weathering are the source of the forming borates; the borates can be formed in various brines of the different concentrating stages of sulfate and carbonate types; the precipitation of borates requires a rather stable environment; the mixing process and low-temperature condition are fairly beneficial for the borate formation; and the formation of borates is closely related to the chemical type, pH value, and B-content of those brines.¹⁵

Boron mineralization occurs in Yuanjiaguo iron ore bodies of Kuandian-type. One of the features of the Kuandian-type iron ore deposits is that they consistently occur at the same position in the stratigraphy. The Precambrian metamorphic systems in the east Liaoning region can be divided into the Anshan Group (Archaen), the Kuandian Group (Lower Proterozoic), and the Liaohe Group (middle Proterozoic). The iron ore and associated boron deposits occur in the Yangmugan Series and the Baiciadi Series of the Kuandian Group, all of which consist of tourmaline granulite, biotite, garnet, magnesium marble, and plagioclase hornblende. The boron-magnesite minerals were formed from the remnant solution after rock-forming and iron-ore-forming stages. Therefore, all iron deposits are associated with deposits of boron, phosphorous, sulfides, and rare earths.¹⁶

Iran.—At Deh-e-Shotoran near Sirjan, the region is of tourmaline-rich granites that have invaded metamorphosed sandstones. Ulexite is found in depressions. At Tonkar near Sabzevar, there are several sources of borates in consolidated sediments of thin beds of limestone, marl, and clays. Ulexite also occurs close to the village of Ashin near Anarak.¹⁷

Mexico.—U.S. Borax and Vitro Corp. operated a pilot plant to evaluate a borate deposit near Magdalena in Sonora during 1991.

Negotiation began that could lead to a North American Free-Trade Agreement among Canada, Mexico, and the United States. The talks concerned the investment and ownership of corporations.

Turkey.—Turkey's boron operations are under the control of the Government corporation, Etibank, that mines boron from major deposits at Bigadic, Kirka, and Emet. Etibank operates refining facilities to produce refined sodium borates and boric acid from tincal concentrates at Bandirma. Boron minerals and compounds are shipped from the port of Bandirma on the Sea of Marmara and Izmir on the Aegean Sea.

During 1991, studies on the beneficiation of boron minerals by flotation were investigated. Calcium-containing borates are relatively insoluble, while sodium-containing borates are highly soluble. Flotation tests were conducted to elucidate the mechanism involved in the flotation of boron minerals.¹⁸

U.S.S.R.—Several distributors were marketing boron compounds produced in the U.S.S.R. Among the materials listed were boric acid, borax decahydrate, anhydrous borax, sodium perborate, and calcium borate.¹⁹

United Kingdom.—A high-speed composite lifeboat, the first prototype of a successor to the Royal National Lifeboat Institution Arun boat, began sea trials. The new craft is almost 1.5 tons lighter while increasing the design strength. The reinforcement was a woven combination of a amid nylon with e-glass, which is a borosilicate-type glass. The first prototype exceeded contract speeds.²⁰

Yugoslavia.—Boron in the Janando basin in Serbia occurs as haulite (44% boron oxide), and in the Kremna basin in Serbia and the Lopari-Sibosnica basin in Bosnia as searlesite.

In the volcanic sedimentary series of the Jarando Neogene basin, haulite mineralization was discovered near the Pobrdjski Potok, about 1 kilometer north

of the magnesite deposit at Bela Stena. Haulite occurs in a series of lenses up to 1 meter thick and 10 meters long. In the sedimentary deposit of pellitomorphic magnesite and dolomite at Kremna (Serbia) of Neogene age, searlesite appears in the form of ball-shaped grains. In some magnesite layers, the percentage of searlesite is as much as 40%, with an average boron oxide content of 1.6%. In Bosnia, in the Miocene lacustrine sediments of the Lopari-Sibosnica basin, ellipsoidal lumps of searlesite are found in shale-marl series with interlayers of tuffs and tuffaceous sandstone.²¹ (See table 10.)

Current Research

Atochem S.A. granted Morton International worldwide licensing rights to a new pulp process. The process combines the use of a reducing agent, such as "Boral," which contains sodium borohydride, with Atochem's hydrogen peroxide. The new process enables economic achievement of brightness levels of 1% to 2% International Standards Organization (ISO) over those obtained by the conventional process.²²

The occurrence of boracite and other boron-bearing minerals in the Gulf Coast Salt Basin was reported in 1987. In Wayne County, MS, 72 wells have been drilled to the Louann Salt formation at depths of between 12,000 and 15,000 feet. Cuttings from nine wells have provided boron-bearing minerals. Boracite occurs as small euhedral crystals in clear, pale yellow, or pale bluish-green. The apparent consistent occurrence of the boron-bearing minerals in the study area suggests that their presence may be pervasive at the top of the Louann Salt throughout the entire Salt Basin.²³

A study of 78 wells from a 4-county area of Mississippi provided borocite group crystals from only 5 wells. The boracite-containing wells are distributed randomly.²⁴

Argonne National Laboratory won a 1991 Research and Development 100 Award for the development of boric acid lubricant. The lubricant is extremely versatile with applications in moving

mechanical seals; sliding, rolling, and rotating engine parts; and metal-forming and metal-curing machines. It can be used to prevent damage to heavily loaded gears and to railroad trucks and wheels. It also has value for high-precision motion drives where stick-slip is a major concern, as well as magnetic data storage media and many other applications.²⁵

A new composite thermal-protection system was developed by Ames Research Center that used silica and boron oxide powders, which form borosilicate glass, and silicon tetraboride powder, which gives the requisite emittance. The ingredients are mixed in an alcohol carrier to make a slurry, which is strayed on a tile, dried, and sintered to form a hard, protective surface. The resulting system had thermal insulating properties comparable to existing systems but with 20 to 100 times more resistance to impact.²⁶

The use of "thinnings," the small trees cut in commercial forest that are cut so that the best trees may grow larger, were used in two revolutionary new buildings in Dorset, England. Thinnings are considered too small for construction and are usually used for wood-burning stoves or for mulch. The new building approach can spare and preserve forest by making productive use of their thinnings. Norway spruce used in the buildings was borate-treated for longer working life. The preservative was a strong, warm solution of disodium octaborate tetrahydrate. The debarked trees were dunked in groups of three or four in 30-foot tanks. Longer trees were sprayed three times to achieve 100% borate penetration.

The green flexibility of newly felled treated wood was considered an asset. Stored in polythene, the thinnings retain flexibility for a month. While sawing wood weakens the grain, which gives tensile strength to the beam, thinnings have the same strength as sawn wood twice its age. The new buildings were designed to exploit the strength in tension of roundwood and reduce the strength demands at midpoint.²⁷

Studies on the role of boron in granitic magmas demonstrated that boron is

concentrated in late-stage magmas until lost through aqueous vapor. Boron clusters in the melt scavenge water and alkalis. The effects on magmas may influence the concentration and precipitation of metal ores and the development of crystals in granite-pegmatite systems.²⁸

The texts of the plenary and invited lectures presented at the 7th International Symposium on Boron Chemistry (IMEBORON) held in Torun, Poland, July 30-August 3, 1990, were published in the March 1991 issue of *Pure and Applied Chemistry*. More than 100 participants from 13 countries attended the meeting. The scientific program consisted of 7 plenary and 18 invited lectures and 35 oral and 32 poster presentations. A panel discussion focused on current trends in practical applications of boron compounds. The 8th IMEBORON was scheduled at the University of Tennessee for July 11-15, 1993.

OUTLOOK

Production and consumption of boron minerals and compounds have decreased between 1982 and 1991. There are several factors that may lead to misleading outlooks in consumption. One is that production and imports reported in 1 year may be utilized over a period of years. In addition, environmental concerns may change the demand for boron significantly in a short period. The regulation of fire retardants in products have resulted in changes in boron usage as a fire retardant. More recent decreases in domestic consumption have been attributed to decreases in glass consumption because of less demand resulting from a recession.

Agriculture

Boron usage in agriculture reached a low in 1982 and has continued to decline. The primary reason was attributed to the decline of the number of farms during the same time period. Farming exports are showing increased strength and demand for boron usage in agriculture.

Ceramics and Glass

Boron usage increased over the 1980's, reaching a peak in 1984 that was a 36% increase over that of the prior year. This spike was probably a demand to balance the sharp decline of 1982 of 41%. Ceramics and glass have both faced competition with polymers. The U.S. fiberglass industry was reported to be feeling the effects of recessionary pressures. The sagging economy produced a decline in demand for fiberglass reinforcements that was expected to be long term. Fiberglass is closely related to construction and transportation, which continue to be depressed.

Coatings and Plating

Primarily used as a protective coating for steel products and as a glazing on ceramic tiles, usage has experienced a decline. This decline was a result of the demand for polymers that replace many of the coatings and plating uses.

Fabricated Metal Products

Boron usage decreased in metal products during the past decade. Many traditional metal products that require soldering now are produced from polymers as one piece. Usage in specialized metal was expected to increase at the rate of 2% per year.

Soaps and Detergents

This usage declined primarily as chlorine bleaches and cold water washes replace boron soap powders. Recent concern for environmental effects of chlorine may reverse the decline. Perborate bleaches have returned to name brand soap products. The usage of boron in soaps and bleaches was expected to increase by 4% per year over the next 5 years.

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TABLE 1
SALIENT STATISTICS OF BORON MINERALS AND COMPOUNDS

(Thousand metric tons and thousand dollars)

	1987	1988	1989	1990	1991
United States:					
Sold or used by producers:					
Quantity:					
Gross weight ¹	1,256	1,149	1,114	1,094	1,240
Boron oxide (B ₂ O ₃) content	625	578	562	608	626
Value	\$475,092	\$429,667	\$429,806	\$436,175	\$442,532
Exports:					
Boric acid: ²					
Quantity	61	56	42	39	47
Value	\$34,180	\$35,301	\$32,613	\$31,679	\$35,457
Sodium borates:					
Quantity ³	552	546	646	585	554
Value ⁴	\$243,600	\$240,800	\$361,000	\$208,433	\$205,722
Imports for consumption: ⁴					
Boric acid:					
Quantity	2	3	3	6	5
Value	\$2,900	\$2,020	\$2,197	\$3,921	\$3,784
Colemanite:					
Quantity	7	17	15	12	18
Value	\$2,763	\$7,790	\$4,202	\$3,310	\$4,389
Ulexite:					
Quantity	47	31	27	29	16
Value	\$20,597	\$7,480	\$1,552	\$7,360	\$4,060
Consumption: Boron oxide (B ₂ O ₃) content	335	356	315	319	261
World: Production	2,685	2,926	2,936	2,966	2,988

¹Estimated. ²Revised.

³Minerals and compounds sold or used by producers, including both actual mine production and marketable products.

⁴Includes orthoboric and anhydrous boric acid.

⁵The Journal of Commerce Port Import/Export Reporting Service.

⁶Boron oxide (B₂O₃) content. In addition, borax imports from Turkey were 4,356 tons in 1987, 8,165 tons in 1988, and 7,257 tons in 1989.

TABLE 2
BORON MINERALS OF COMMERCIAL IMPORTANCE¹

Mineral	Chemical composition	B ₂ O ₃ weight percent
Boracite (stassfurtite)	Mg ₆ B ₁₄ O ₂₆ Cl ₂	62.2
Colemanite	Ca ₂ B ₆ O ₁₁ •5H ₂ O	50.8
Hydroboracite	CaMgB ₆ O ₁₁ •6H ₂ O	50.5
Kernite (rasortie)	Na ₂ B ₄ O ₇ •4H ₂ O	51.0
Priceite (pandermite)	Ca ₂ B ₁₂ O ₂₃ •9H ₂ O	49.8
Probertite (kramerite)	NaCaB ₃ O ₉	49.6
Sassolite (natural boric acid)	H ₃ BO ₃	56.4
Szaibelyite (ascharite)	MgBO ₂ (OH)	41.4
Tincal (natural borax)	Na ₂ B ₄ O ₇ •10H ₂ O	36.5
Tincalconite (mohavite)	Na ₂ B ₄ O•5H ₂ O	47.8
Ulexite (boronatrocaltite)	NaCaB ₃ O ₉ •8H ₂ O	43.0

¹Parentheses include common names.

TABLE 3
TIME-PRICE RELATIONSHIPS
FOR BORAX PENTAHYDRATES¹

Year	Average annual U.S. producer price (dollars per metric ton)
	Actual prices
1972	83
1973	88
1974	108
1975	116
1976	121
1977	130
1978	141
1979	184
1980	186
1981	205
1982	222
1983	222
1984	229
1985	236
1986	243
1987	249
1988	249
1989	259
1990	249
1991	247

¹Borax pentahydrate, technical, granular, 99.5%, bulk, carlots, works.

TABLE 4
U.S. CONSUMPTION OF BORON
MINERALS AND COMPOUNDS, BY
END USE

End use	(Metric tons of boron oxide content) ¹	
	1990	1991
Agriculture	5,787	5,712
Borosilicate glasses	27,905	29,504
Enamels, frits, glazes	7,882	5,878
Fire retardants:		
Cellulosic insulation	11,741	11,662
Other	1,401	1,769
Glass-fiber insulation	95,059	82,395
Metallurgy	2,554	3,518
Miscellaneous uses	14,586	16,693
Nuclear applications	546	546
Soaps and detergents	24,230	22,848
Sold to distributors, end use unknown	71,670	36,264
Textile-grade glass fibers	55,698	45,067
Total	319,059	261,212

¹Includes imports of borax, boric acid, colemanite, and ulexite.

TABLE 5
U.S. CONSUMPTION OF
ORTHOBORIC
ACID, BY END USE

(Metric tons of boron oxide content)¹

End use	1990	1991
Agriculture	108	61
Borosilicate glasses	4,920	4,776
Enamels, frits, glazes	1,013	641
Fire retardants:		
Cellulosic insulation	1,647	1,516
Other	1,401	1,769
Insulation-grade glass fibers	1,682	1,935
Metallurgy	393	594
Miscellaneous uses	8,948	8,805
Nuclear applications	544	544
Soaps and detergents	50	127
Sold to distributors, end use unknown	24,204	13,753
Textile-grade glass fibers	19,482	19,473
Total	64,392	53,994

¹Includes imports.

TABLE 6
YEAREND 1991 PRICES FOR BORON MINERALS AND COMPOUNDS
PER METRIC TON¹

Product	Price, December 31, 1991 (rounded dollars)
Borax, technical, anhydrous, 99%, bulk, carload, works ²	690- 698
Borax, technical, anhydrous, 99%, bags, carload, works ²	652
Borax, technical, granular, decahydrate, 99.%, bags, carload, works ²	259- 379
Borax, technical, granular, decahydrate, 99.5%, bulk, carload, works ²	214
Borax, technical, granular, pentahydrate, 99.5%, bags, carload, works ²	292
Borax, technical, granular, pentahydrate, 99.5%, bulk, carload, works ²	247
Boric acid, technical, granular, 99.9%, bags, carload, works ²	703- 711
Boric acid, technical, granular, 99.9%, bulk, carload, works ²	658- 659
Boric acid, United States Borax & Chemical Corp., high-purity anhydrous, 99% B ₂ O ₃ , 100-pound bags, carlots	2,585
Colemanite, Turkish, 40% to 42% B ₂ O ₃ , ground to a minus 70-mesh, f.o.b. railcars, Kings Creek, SC ³	480
Ulexite, Turkish, 37% B ₂ O ₃ , ground to a minus 100-mesh, f.o.b railcars, Norfolk, VA ³	242

¹U.S. f.o.b. plant or port prices per metric ton of product. Other conditions of final preparation, transportation, quantities, and qualities not stated are subject to negotiation and/or somewhat different price quotations.

²Chemical Marketing Reporter. V. 241, No. 1, Jan. 1992 p. 35.

³American Borates Co.

TABLE 7
U.S. EXPORTS OF BORIC ACID AND REFINED SODIUM BORATE COMPOUNDS, BY COUNTRY

Country	1990			1991		
	Boric acid ¹		Sodium borates ² (metric tons)	Boric acid ¹		Sodium borates ² (metric tons)
	Quantity (metric tons)	Value (thousands)		Quantity (metric tons)	Value (thousands)	
Australia	967	\$729	7,401	1,205	\$918	9,626
Bangladesh	—	—	32	—	—	—
Belgium-Luxembourg	—	—	425	1,628	965	40
Brazil	113	89	2,126	166	145	2,039
Canada	5,682	3,500	41,929	4,834	3,043	36,446
China	—	—	175	27	11	1,679
Colombia	137	109	3,837	140	119	1,164
Costa Rica	—	—	2,593	32	27	2,197
Dominican Republic	374	203	11	10	14	45
Ecuador	—	—	1,119	—	—	1,096
Egypt	—	—	—	—	—	554
El Salvador	—	—	24	—	—	5
Finland	244	144	199	—	—	18
France	88	44	1,224	—	—	191
Germany	119	88	92	16	44	124
Guatemala	1,466	562	82	3	3	37
Haiti	—	—	224	—	—	368
Honduras	46	16	41	40	46	70
Hong Kong	253	263	2,984	463	459	3,795
Indonesia	256	205	7,450	1,423	950	5,529

See footnotes at end of table.

TABLE 7-Continued
U.S. EXPORTS OF BORIC ACID AND REFINED SODIUM BORATE COMPOUNDS, BY COUNTRY

Country	1990			1991		
	Boric acid ¹		Sodium borates ² (metric tons)	Boric acid ¹		Sodium borates ² (metric tons)
	Quantity (metric tons)	Value (thousands)		Quantity (metric tons)	Value (thousands)	
Israel	104	\$93	290	57	\$53	224
Jamaica	2	6	10	1	3	2
Japan	15,999	12,875	39,064	18,214	15,423	43,742
Korea, Republic of	1,472	1,238	19,200	5,224	3,169	18,965
Malaysia	154	113	7,268	404	238	7,357
Mexico	2,282	1,622	24,531	3,481	2,055	28,767
Netherlands	4,382	5,823	349,968	1,098	2,117	318,823
New Zealand	485	350	3,040	323	219	2,057
Pakistan	—	—	409	129	63	135
Panama	2	8	79	1	3	26
Papua New Guinea	—	—	80	16	10	—
Peru	3	3	18	—	—	172
Philippines	—	—	2,075	632	341	1,830
Saudi Arabia	31	44	22	—	—	—
Singapore	261	195	1,920	1,109	634	1,632
South Africa, Republic of	47	52	1,762	517	94	2,318
Spain	202	126	43,345	6	13	38,530
Taiwan	2,962	2,390	15,291	4,058	2,885	14,879
Thailand	544	457	2,380	784	641	4,453
Trinidad and Tobago	—	—	6	—	—	—
United Kingdom	211	120	1,171	135	91	1,506
Uruguay	7	6	5	—	—	15
Venezuela	152	128	469	913	616	1,673
Zimbabwe	—	—	49	—	—	226
Other	91	78	535	18	45	1,475
Total³	39,138	31,679	584,955	47,107	35,457	553,830

¹Bureau of the Census: Harmonized Code 2440.11.

²Bureau of the Census: Harmonized Codes 2840.19, 2840.30, and 2840.20.

³Data may not add to totals shown because of independent rounding.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF BORIC ACID, BY COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)
Brazil	20	\$15	—	—
Canada	38	52	26	\$16
Chile	2,487	1,208	1,298	641
France	55	36	1	1
Germany, Federal Republic of	4	4	9	6
Italy	2,841	2,397	3,066	2,641
Japan	88	159	35	150
Netherlands	—	—	21	12
Turkey	—	—	400	210
United Kingdom	25	50	95	107
Total	5,558	3,921	4,951	3,784

¹U.S. Customs declared values.

Source: Bureau of the Census.

TABLE 9
WORLD BORON ANNUAL
PRODUCTION CAPACITY,
DECEMBER 31, 1991

(Thousand metric tons of boron oxide content)

Country	Capacity
North America: United States	735
South America:	
Argentina	28
Bolivia	24
Chile	5
Peru*	5
Total	62
Europe: CIS*	41
Asia:	
China*	5
Turkey	560
Total	565
World total²	1,400

*Estimated.

¹Includes capacity at operating plants as well as plants on standby basis.

²Data do not add to total shown because of independent rounding.

TABLE 10
BORON MINERALS: WORLD PRODUCTION, BY COUNTRY¹

(Thousand metric tons)

Country	1987	1988	1989	1990	1991*
Argentina	185	270	261	260	250
Bolivia (ulexite)	—	1	10	3	² 14
Chile	13	32	131	132	130
China*	27	27	27	27	27
Iran (borax) ³	1	1	(⁴)	2	2
Peru*	² 23	15	18	¹ 15	15
Turkey ⁵	980	1,231	1,175	¹ 1,253	1,150
U.S.S.R.*	200	200	200	¹ 180	160
United States ⁶	1,256	1,149	1,114	1,094	² 1,240
Total	²2,685	²2,926	²2,936	²2,966	2,988

*Estimated. ¹Revised.

²Table includes data available through May 11, 1992.

³Reported figure.

⁴Data are for years beginning Mar. 21 of that stated.

⁵Less than 1/2 unit.

⁶Concentrates from ore.

⁷Minerals and compounds sold or used by producers, including both actual mine production and marketable products.

BROMINE

By Phyllis A. Lyday

Mrs. Lyday, a physical scientist with the U.S. Bureau of Mines, has been the commodity specialist for bromine for 13 years. Domestic survey data were prepared by Gail Mason, statistical assistant; and international data tables were prepared by Doug Rhoten, international data assistant.

Production of bromine worldwide in 1991 was as follows: United States, 42%; Israel, 32%; the U.S.S.R., 12%; the United Kingdom, 7%; and other countries, 7%. The U.S. portion of world production has decreased steadily since 1973, when the United States produced 71% of the world supply. The decrease in world share has been a result of environmental constraints and the emergence of Israel as the world's second largest producer. Domestic capacity decreased 14% during the same period of time. The quantity of bromine sold or used in the United States was 170 million kilograms (kg) valued at \$167 million. Exports of elemental bromine and bromine contained in compounds amounted to 17 million kg. The price of elemental bromine in bulk was 56 cents per kg. Primary uses of bromine compounds were in flame retardants (27%), agriculture (15%), petroleum additives (15%), well-drilling fluids (10%), and other (33%).¹

DOMESTIC DATA COVERAGE

Domestic production data for bromine were developed by the U.S. Bureau of Mines from a voluntary survey of U.S. operations. Of the six operations to which a survey request was sent, two responded, representing 41% of total elemental bromine sold or used. Production at the other four operations was estimated by using quantity of brine produced and estimated bromine concentration. (See table 1.)

BACKGROUND

Definitions, Grades, and Specifications

In the elemental form, bromine is a very dark, reddish-brown liquid. Bromine is the only nonmetallic element that is liquid at ordinary temperature and pressure. The natural form of bromine is a solution of sodium bromide in natural brines, saline deposits, salt lakes and seas, and oceans.

Elemental bromine is marketed in a "purified" grade with the following specifications: Specific gravity not less than 3.1 at 10° C to 20° C; bromine, not less than 99.7%; iodine, none; and chlorine, not more than 0.1%. Specifications for the various grades of bromine compounds include technical bromine, 99.5% pure, with the chief impurities consisting of chlorine, traces of moisture, and organic matter. Specifications of the United States Pharmacopoeia and the American Chemical Society Committee on Analytical Reagents allow 0.3% chlorine, 0.05% iodine, 0.0002% sulfur (0.006% as sulfate), and no more organic matter in 1 milliliter than will saturate 50 milliliters of 5% sodium hydroxide solution. The term "chemically pure" signifies a minimum of impurities.

Geology-Resources

Bromine is widely distributed in the Earth's crust, but in small quantities. By far the largest potential source of bromine in the world exists in the oceans. At a

concentration of only 65 parts per million (ppm), large amounts of seawater are processed to obtain the bromine.

Arkansas brines contain about 5,000 ppm at depths of 2,286 meters (7,500 feet) in limestone of the Smackover Formation of Jurassic age. In Michigan, brines containing about 2,600 ppm of bromine occur in the Sylvania Sandstone Formation of the Detroit River Group of Devonian age.

In Israel, bromine is produced as a byproduct of salt, sodium chloride, and potash production from the Dead Sea. The waste brines contain 14,000 ppm bromine.

Technology

Processing.—The Arkansas Geological Commission report three east-west bromine-rich brine fields. Wells are drilled down to the brine level, and a submersible pump is lowered to pump the liquid to the surface. Brine is separated by gravity from any residual gas at the surface and pumped to one of six processing facilities.

At the processing facility, bromine is separated from the brine by a steaming-out process. The brine is pumped into the top of a tower constructed of granite and filled with ceramic packing. As the brine falls through the packing material, it reacts with chlorine and steam that are injected at the bottom of the tower. One pound of chlorine yields 1 kg of bromine. About 95% of the bromine, or about 0.7 to 0.8 kg of bromine per barrel of brine, is recovered if the raw brine is first acidified to a pH of 3.5. The chlorine

replaces the bromine in the brine, and the gaseous bromine rises with the steam out of the top of the tower; there it is condensed to a reddish-brown liquid. Bromine is separated from gases. The bromine liquid can be further purified or reacted with other materials to form bromine compounds. Bromine vapor, a little chlorine, and water vapor are captured at the top of the tower. Hot bromine-free liquor emerges from the bottom of the tower. After neutralizing with lime, the waste liquor is pumped through a heat exchanger to a waste pond. Brine from the pond is reinjected into the same producing zone to maintain hydrostatic pressure.

Seawater contains about 60 ppm to 70 ppm of bromine as sodium bromide or magnesium bromide. Production of bromine from seawater uses the blowing-out process. Raw seawater is acidified by adding sulfuric acid and then chlorine. Air was drawn into the base of the tower and rises as the brine descends. Air containing bromine passes to the absorption tower. In the absorption tower, bromine reacts with sulfur dioxide to form a hydrogen bromide. The bromine is separated by adding acid to the solution and is distilled by steam. The gaseous bromine is condensed, separated, and purified.

Recycling.—Great Lakes Chemical Corp. (Great Lakes) announced the beginning of what is claimed to be the first halon reclamation and recycling facility. Great Lakes planned to collect and recycle used halon from the fire services industry through E/M Corp., a wholly owned subsidiary. The first facility was to be in the Los Angeles basin and will serve west coast and Pacific Rim markets. A second site was to be at El Dorado, AR.²

Byproducts and Coproducts

Some bromine-bearing brines contain hydrogen sulfide gas. This gas has a disagreeable odor, is highly toxic, and when burned, will oxidize to sulfur dioxide, an acid-producing gas. To prevent the emission of the gas to the

atmosphere where sulfur dioxide may form, environmental regulations require the recovery of the sulfur. Hydrogen sulfide gas was chemically removed from the incoming brine and converted into elemental sulfur or other nontoxic sulfur-containing compounds. The cost of recovery was greater than the selling price of the sulfur, but recovery prevented emission of a gas that may contribute to the formation of acid rain.

Substitutes

Various materials are used in flame retardants as replacements for bromine in engineering and high-performance thermoplastic polymers and blends, and polymeric composites. The distinguishing characteristic of engineering polymers is that they have properties that lend themselves to structural applications over a wide range of temperatures, high mechanical stress, and harsh chemical and physical environments. The high-performance polymers are also distinguished by their special properties such as extremely high-temperature tolerance and outstanding optical properties or conductivity, but they are not necessarily designed for structural integrity.³ (See table 2.)

Economic Factors

Costs.—Oil & Gas Journal published in the December 30, 1991, issue that drilling and/or equipping costs for gas wells in Arkansas averaged \$486,000 for wells 1,524 to 2,286 meters deep (5,000 to 7,499 feet). Chlorine, the largest manufacturing cost factor, represented about 30% of the manufacturing cost of bromine. Other cost factors include brine (22%), operating cost (15%), utilities (14%), overhead (12%), and other (7%).

Taxes.—During 1991, brines produced in Arkansas required the payment of \$2 per 1,000 barrels in severance taxes, and capital equipment was subject to the payment of property taxes. Bromine produced in the United States was subject to Superfund taxes of \$4.91 per metric

ton (\$4.45 per short ton). Bromine was manufactured using chlorine, which was subject to a Superfund tax of \$2.98 per metric ton of chlorine (\$2.70 per short ton).

Depletion Provisions.—Bromine producers (domestic and foreign) are granted a 5% depletion allowance under the Federal Income Tax Law on the value of bromine produced from brine wells. The depletion allowance can be calculated by the actual cost method.

Operating Factors

Toxicity.—Bromine is highly toxic and corrosive and must not be allowed to escape into the atmosphere. Many bromine compounds are also poisonous or irritating and must be packaged in leakproof containers to avoid personal injury. If bromine spills on paper, rags, wood shaving, etc., it will generate considerable heat, which may lead to spontaneous combustion. Bromine reacts with living tissue and must be removed immediately to avoid serious injury.

Bromine vapors are hazardous to the eyes and lungs. Any concentration above 1 ppm in the air for an 8-hour exposure is considered a health hazard. Bromine can be detected by its odor even at this level. Exposure to concentrations of 500 to 1,000 ppm for as little as one-half hour is lethal. The Occupational Safety and Health Administration regulates the working conditions of bromine plants.

When handling bromine, a person should use safety goggles, face shield, rubber gloves, rubber boots, and under some conditions, a self-contained breathing apparatus. Bromine spills are neutralized with a solution of sodium thiosulfate. Gaseous bromine is neutralized with controlled amounts of gaseous ammonia. All metal, such as electrical switches and connections, that may be exposed to bromine vapors should be made of corrosion resistant materials and/or completely sealed from contact with the room air.

Employment.—The U.S. bromine chemical industry employed directly an average of 20 personnel for each \$1 million of sales. The employees work in production, packaging, transportation, marketing, product and process development, quality control, and administration. More than two-thirds of these jobs was concentrated in Union and Columbia Counties of south Arkansas.

Energy Requirements.—The manufacturing cost of bromine was heavily dependent on chlorine and brine cost. Of the total brine cost, 46% was power related and 53% was maintenance cost. Brine cost is dependent on well maintenance cost and energy cost associated with well pumping. Approximately 14% of the bromine manufacturing cost was energy related.

Transportation.—The Research and Special Programs Administration (RSPA), U.S. Department of Transportation (DOT), published rules for hazardous substances (49 CFR, parts 171 and 172). The action complies with a 1986 amendment (Public Law 99-499) to section 306(a) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 (Public Law 96-510). The law mandates that RSPA regulate all Environmental Protection Agency (EPA)-designated hazardous substances. The amendment required shippers and carriers to identify CERCLA hazardous substances, to comply with the Hazardous Materials Regulations, and to make the required notifications if a discharge of a hazardous substance occurs.

ANNUAL REVIEW

Legislation and Government Programs

The Federal Trade Commission (FTC) opposed Great Lakes's proposal to acquire the remaining 50% interest in Arkansas Chemicals Inc., which is a joint venture with PPG Industries Inc. The FTC objected because the sale could

lessen competition in the bromine markets.⁴

The DOT RSPA listed a final rule for performance-oriented packaging standards that included several bromine compounds under Hazardous Material Regulation (HMR) (49 CFR, parts 173.193 and 228). The rule comprehensively revises the HMR with respect to hazard communication, classification, and packaging requirements.⁵ On January 1, 1991, the new DOT/United National Performance Oriented Packaging Standards (POPS) were phased into the current DOT HMR. On that date, compliance with domestic shipping was voluntary. However, shipping materials internationally or domestically by air or international waters must comply with the POPS regulations. POPS involves changes to every aspect of shipping activities, including selecting packages; preparing shipping documents; and labeling, marking, and placarding shipments of hazardous materials and waste.⁶

The Department of Health and Human Services and EPA listed a revised priority list of hazardous substances that was to be the subject of toxicological profiles that included brominated compounds. The CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA), established certain requirements for a list of at least 100 hazardous substances that are most commonly found at facilities on the National Priorities List.⁷

An EPA-funded computer network began in May that would allow States to exchange technical and legal information about Superfund programs. Through a computer bulletin board, users would have access to four data bases: a listing of more than 650 EPA policies and guidance documents; State Superfund program information; State settlement, including information on contaminants, technologies, costs, and timetables; and a record of State decisions.⁸

Methyl bromide was dropped by EPA as an inert product on List 2 and was classified as a List 1 inert. The Agency stated that all products containing methyl bromide as an inert have been canceled.⁹

EPA announced in the Federal Register a final rule for the pesticide tolerances for inorganic bromide resulting from fumigation with methyl bromide on May 1, 1991. Tolerances contained in 40 CFR 180.123 and 199 for residues of inorganic bromides in or on ginger roots was amended to 100 ppm.

A section 18 exemption was granted by the EPA to the U.S. Department of Agriculture (USDA) for the use of methyl bromide to control various plant pests not currently established in the United States on imported cherimoya. The exemption provisions included: application under tarpaulins or in other temporary enclosures at the rate of 3 pounds per cubic foot, held for 2 hours; detection of leaks using masks and monitoring; limitation of 30-ppm maximum residue for inorganic bromides and 0.01 ppm for residues of ethyl bromide; aeration of treated commodities to allow dissipation of methyl bromide residues; an expiration date of October 10, 1994.¹⁰

A notice of proposed rulemaking was published by the EPA in the Federal Register September 30, 1991, to conform its stratospheric ozone protection regulations (40 CFR, part 82) to the requirements of title VI of the Clean Air Act Amendments of 1990, Public Law 101-549. The notice proposes amended regulations implementing the 1992 and later requirements of section 604, as well as the related provisions of sections 603, 607, and 616, in a manner consistent with the United States' continuing obligations under the Montreal Protocol as amended.

A proposed rule was published by the EPA in the Federal Register on June 25, 1991, for a test under section 4(a) of the Toxic Substances Control Act (TSCA) in response to the Interagency Testing Committee (ITC) designation of five brominated flame retardants (BFR). The testing would include environmental and health effects and chemical fate testing. EPA has concluded that activities involving these BFR may pose an unreasonable risk of injury to human health or the environment as suggested by certain preliminary data, existing data are inadequate to assess the risks to human health and the environment posed by

exposure to these substances, and testing of each of the five BFR's is necessary to develop such data.

Production

Ethyl Corp. and Great Lakes produced and marketed bromine chemicals from plants in Arkansas. Small amounts of unpurified bromine were produced as a byproduct of magnesium production in Michigan and reprocessed for consumption in Arkansas. The Arkansas plants accounted for 97% of U.S. elemental bromine capacity at yearend 1991 and 100% of bromine sold or used.

Plant capacity was dependent upon brine supplies, concentration of the bromine in the brine, and individual plant extraction processes. In Arkansas, one supply and one disposal well were required for each 4.5 million kg per year of bromine produced.

Bromine concentrations in the brine decrease as waste brine depleted of bromine is returned to its source. New wells must be drilled to provide adequate reserves to ensure future demands of elemental bromine. Each supply well requires an investment in excess of \$1 million and has an average life of about 10 to 15 years. (See table 3.)

Consumption and Uses

Fire retardants were primarily tetrabromobisphenol-A (TBBA) and decabromodiphenyl oxide. Great Lakes announced plans to expand TBBA production capacity at its El Dorado, AR, facility to meet growing demand as a flame retardant for acrylonitrile-butadiene-styrene (ABS) polymers. The expansion increased Great Lakes' capacity by 25%.

The U.S. International Trade Commission (USITC) publication entitled "Synthetic Organic Chemicals, 1990" listed Ethyl Corp. as the only producer of hexabromocyclododecane. Sales of flame retardants account for one-half of the worldwide plastic additives market and are growing. Brominated hydrocarbons are the major materials used to make flame retardants.

Demand for ethylene dibromide (EDB) is in gasoline additives as a scavenger for lead antiknock. The USITC's "Synthetic Organic Chemicals, 1990" listed Great Lakes and Ethyl as the only producers of EDB used in gasoline additives during 1991.

The USITC reported that the Dyes & Pigments Div. of Mobay Chemical Corp. produced pigment red 168, dibromoanthranthrone orange. Red 168 was used in automotive metallic applications because of its transparency.

Bromine was used in clear brine drilling fluids used in work-over and completion fluids and other uses. Hoechst Celanese Corp. (U.S.) sold bromine compounds as intermediates in the production of antibiotics, disinfectants, anti-inflammatory, and analgesic products. One bromine compound is a useful intermediate under both alkaline and acidic conditions. Another compound is useful for heteroatomic ring closures of organic chemicals. In addition, the company used bromine in dyes.

Halogenated synthetic rubber consumption has grown between 1980 and 1992. Exxon Chemical Co. is the only domestic manufacturer of bromobutyl rubber. This rubber is more heat resistant than other types of rubber and is used primarily in truck tires. The International Institute of Synthetic Rubber Producers in Houston, TX, projected growth rates of 2.1% per year through 1996 for all synthetic rubber consumption, with the exception of polychloroprene.

Prices

Bromine was sold under contracts negotiated between buyer and seller. Price quotations do not necessarily represent prices at which transactions actually occurred, nor do they represent bid and asked prices. They were quoted in table 4 to serve only as a guide to yearend price levels. (See table 4.)

Foreign Trade

Israel received duty-free treatment on its bromine products in all major world

markets except the United States, where duties are paid on three significant bromine products. The duty on all bromine products will drop to zero in 1995. (See tables 5 and 6.)

World Review

Capacity.—The data in table 7 are rated capacity for mines and refineries as of December 31, 1991. (See tables 7 and 8.)

Canada.—Ethyl Corp. applied for permits to double and modernize its 22,680-metric-ton-per-year plant for tetraethyl lead (TEL) at Corunna, Ontario, by 1992. TEL uses a bromine compound as a scavenger for the lead. Farm vehicles and light aircraft are exempt from a phaseout of leaded gasoline passed in 1988 that took effect in December 1990. Local unions are in favor of the plant expansion because it will employ 350 for the construction and create 70 to 80 new plant jobs. The plant presently employs 165 people. The expansion was expected to cost \$67 million. The modernization would decrease lead emissions by 23% and improve air quality emissions from the plant by a 53% decrease.¹¹

China.—The Qaidam Basin in northwest China's Qinghai Province covers an area of 25,000 square kilometers and contains reserves of 40 types of salt minerals that include bromine, lithium, and magnesium. A potash plant was in operation in the southern portion of the basin, and a soda ash plant was planned to begin production in 1991.¹²

Germany, Federal Republic of.—The closure of eastern and western potash mines was proposed by a federal-state commission. BASF Corp.'s minerals subsidiary Kali und Salz announced plans to cooperate with eastern German potash and salt producer Mitteldeutscher Kali (MDK). Almost 5,000 jobs were to be eliminated in the German potash industry by 1994, including 1,400 out of 7,300 jobs at Kali und Salz and 3,500 out of

12,000 at MDK. Bromine was produced from the bitterns of potash production from mines that also have bromine production plants. The production of bromine could be adversely affected by the closures.¹³

Great Lakes acquired the chemical plant at Konstanz of Degussa AG effective October 1. Plans were underway to relocate the research and development from Aycliffe, United Kingdom, to Konstanz. Great Lakes planned to continue to make amino acid derivatives for Degussa and expand into new bromine and nonbromine products at the newly acquired plant.¹⁴

Israel.—Dead Sea Bromine (DSB), a subsidiary of Israeli Chemicals Ltd. (ICL), announced capacity increases in chlorine and bromine output. The addition of chlorine is necessary to produce bromine. The company planned to increase bromine capacity from 135,000 to 170,000 metric tons per year by 1993. Plans were to reach 200,000 metric tons per year by 1997. DSB planned to invest about \$40 million per year over the next 5 years to increase bromine capacity.¹⁵

The Government began efforts to sell a share of ICL to offset an investment program in 1985. In 1986, ICL announced privatization of some of the 189 State-owned companies. Much of the organic and inorganic chemical activity takes place within the framework of the massive ICL, which in 1986 was composed of 28 companies with a work force of 7,000. During 1990, formal bids were accepted for 50% of ICL, but a number of Government representatives favored a public sell rather than to a foreign investor. Great Lakes was part of the only foreign consortium that had a bid on ICL at yearend 1990.

In August 1991, privatization terms for ICL were agreed to by a committee with representatives from the finance, trade and industry, and justice ministries of the Israeli Government. Some conditions for the privatization appear to conflict in terms of how much control the Government will exercise over ICL. The State retained the "power of supervision"

over the natural resources controlled by ICL, such as bromine and reserves of potash in the Dead Sea. The State has to approve any buyer of a 15% or greater holding or a 26% or larger stake by a strategic partner, such as an international chemicals concern.¹⁶ The plans to sell 51% to a private investor was opposed by company management and members of the Government.

ICL authorized Bromine Compounds to proceed with a \$14 million investment program at Ramat Hovav in the Negev Desert. The investment forms part of a \$45 million plan to produce specialty chemicals for the plastics industry. Technology for the project was developed by ICL's research and development division.¹⁷

DSB Group planned to expand its TBBA used in fire retardants at Beer Sheva by 4,600 metric tons annually. The \$3 million project was to be completed by 1992. In addition to production at Beer Sheva, DSB also produces TBBA at a subsidiary, Broomchemie BV, Terneuzen, Netherlands.¹⁸

Jordan.—The Arab Potash Co. announced that the feasibility study begun in June 1990 was progressing and was expected to be completed by 1992. The initial study was for a \$2 billion complex. The plans were modified to be a \$700 to \$800 million complex to include production of elemental bromine, magnesium oxide, potassium sulfate fertilizers, polyvinyl chloride, soda ash, and some bromine derivatives. The first phase of technical studies was completed and involved three international consultants.¹⁹

U.S.S.R.—The Union of Soviet Socialist Republics (U.S.S.R.) intended to increase production of specialty materials to meet internal demand and win export markets. Alexei Pavlovich, director of the State rubber organization Giprokautchuk, outlined trends at the recent international rubber conference in Ottawa, Canada, organized by the International Rubber Study Group.

The recent opening of the Soviet economy to outside ventures has led to

several projects in the rubber industry. The furthest advance is the Sovbutital joint venture, based in Tobolsk, where a plant is under construction with capacity for butyl rubber and halobutyl rubber.²⁰ The chemical industry was in a recession during 1991. The gross national product was down an estimated 15%, industrial output fell almost 10%, and gross output of chemicals dropped more than 10%.²¹

United Kingdom.—Great Lakes began the purchase of 37% of Associated Octel from Shell, United Kingdom. The purchase will increase Great Lakes' share of Octel to 51%. Octel will continue to diversify, with emphasis on bromine-related specialties. Great Lakes planned to cut the cost of bromine production with retrofits at the company's seawater-based facilities. Bromine from the plant was used in TEL used as an octane booster in leaded gasoline. TEL accounts for 90% of Octel's business.²²

Current Research

Chemists synthesized a reagent by treating a reagent with primary bromides to produce hydroperoxides and peracids. Naturally occurring hydroperoxides are active against cancer, bacteria, and parasites.²³

Ethyl S.A., the European subsidiary of Ethyl Corp., planned to locate a new research and development facility in the Scientific Park at Catholic University of Louvain near Brussels, Belgium. Initial investment will be \$8 million. The company purchased approximately 8 hectares with options to buy an additional 2 hectares in the park.²⁴

Corning Process Systems announced a nonexclusive license to produce bromine from weak solutions of bromide or hydrobromic acid or seawater concentrations.²⁵

Extraction, recovery, and economics for two refractory concentrates of gold were investigated using cyanide and bromine reagents. Gold extractions for cyanide leaching (24 to 48 hours) and bromine leaching (6 hours) were the same and ranged from 94% to 96%. Gold recoveries from bromine pregnant

solutions using carbon adsorption, ion exchange, solvent extraction, and zinc and aluminum precipitation methods were better than 99.9%. A preliminary economic analysis indicates that chemical costs for cyanidation and bromine processes are \$11.70 and \$11.60, respectively, per metric ton of calcine processed.²⁶

Gold was leached with a bromine solution from a very rich (6.2 kg per ton) black sand concentrate and its subsequent recovery by ion exchange resins and solvent extraction. The dissolution of gold from black sand ranged from 94% to 96%. Gold loadings and recoveries of almost 100% were achieved by both ion exchange and solvent extraction methods. The kinetics and equilibrium of loading gold onto ion exchange resins and its elution from the resin were studied. An organic solution was used in all the solvent extraction work for gold recovery from the bromine leach solution. The consumption of the solution was about 130 kg per metric ton of the concentrate processed. The costs of lixiviation to extract 0.0311 kg of gold from the black sand was about \$1.00. The economics of bromine process versus cyanidation were investigated, based on the electrochemical regeneration of bromine.²⁷

The loading characteristics of gold-tetrabromide species onto activated carbon were evaluated using a completely mixed batch reactor system. Although loading continued slowly after several days, abnormally high loading capacity values could be attained within 72 hours. Elution of gold from the loaded carbon was feasible provided the carbon had not been overloaded. If loading is carried to high levels, complete elution becomes impractical and the gold may be recovered by ashing the carbon. The ashing of the carbon appeared to be cost effective. Ashing leads to considerable savings by the elimination of the conventional elution and precipitation methods. Such savings may offset the cost for the high demand of reagent, which is a major disadvantage of the bromine process. Ashing may make the process economically competitive with the cyanide process.²⁸

Ferlini/General Atomics Development Corp. announced plans to transfer its patented flue gas desulfurization process to the commercial market. The process operates in a closed-loop system based on bromine. The sulfur dioxide-containing flue gases are contacted with a dilute solution of commercially available bromine. Sulfur dioxide reacts with the bromine in the solution to form sulfuric acid and hydrogen bromide. Bromine is regenerated from the hydrogen bromide by electrolysis, leaving sulfuric acid and hydrogen, two salable chemicals. Bromine is completely recycled and does not contaminate the environment.

FMC Corp. introduced a calcium peroxide substitute for potassium bromide in dough conditioning formulation. The new material has a finer, more uniform particle size that results in better distribution of the oxidizer with flour and other ingredients. The processing technology also results in reduced moisture content of the stored calcium peroxide, providing better stability and longer shelf life prior to use.²⁹

Chemists at Pennzoil Products Co. developed a new class of synthetic lubricants for extreme service conditions. The lubricants are prepared using alkyl halides such as bromine. The new substance has proved to be effective at extreme temperatures. Although most extreme service applications for lubricants occur in aerospace and military service, there are significant civilian applications in arctic and desert construction projects.³⁰

A new variation of a standard technique to detect amplified DNA sequences was developed using a bromine compound. The technique allows detection of a DNA sequence from outside the reaction tube. The process allows more widespread use of the technique because of high sample count.³¹

OUTLOOK

Sales of bromine, primarily in compounds, have decreased about 25% since 1979. This represents an annual rate of decrease of about 2% per year. These decreases have been offset by

increased use of bromine in fire retardants, sanitizers, and well-drilling fluids. Bromine is expected to increase in demand at the same 1.1% rate through the next 5 years. Demand as a fire retardant will offset any decreases in other uses. Bromine usage in well-drilling fluids was expected to increase.

Petroleum

Demand for bromine as a gasoline additive has declined each year since the EPA issued regulations in the 1970's to reduce the lead in gasoline. Bromine in the form of ethylene dibromide is used as a "scavenger" for the lead to keep the lead from depositing in the engine. In 1979, the amount of bromine sold reached a peak of 225 million kg. The rapid decline to 141 million kg in 1986 was a direct result of the limits on lead in leaded gasoline. During 1991, the European Community continued discussions to reduce lead levels in gasoline.

Federal laws enacted to encourage alternative forms of power in automotive engines are likely to have a depressive effect on increases in petroleum demand. The Clean Air Act Amendments of 1990 (Public Law 101-549) has an amendment that will require mobile sources, such as cars and trucks, to use the most effective technology possible to control emission. Electric cars that do not require bromine gasoline additives are already on the market in California.

Sanitary Preparations

Bromine has found usage in swimming pools, hot tubs, and whirlpools. The sanitary preparation field is an area where bromine has been found to be safer than its substitutes. The use of bromine will continue to grow in this area closely following the gross national product in real growth.

Fire Retardants

Federal regulations covering flammability of private and public building materials and furnishings have

required greater amounts of fire retardant chemicals to be used in these materials and furnishings. Fire retardants are expected to grow as organic materials replace metals in transportation, infrastructure, and packaging. Several State governments continue to support strong consumer laws that protect State residents from products with potential fire hazards produced in other States. Growth during 1991 was reported to be at about 3% to 4%, with sales at about \$860 million in 1990.³²

Other Uses

Usage of calcium bromide and zinc bromide in well-drilling fluids decreased during the 1980's as the domestic petroleum industry suffered a severe recession. Both the Baker Hughes and the Smith rig count published each week in the Oil & Gas Journal showed a 33% to 35% decrease in activity during 1991 when compared with that of 1990. Oilfield chemicals used in drilling, completion and workover, and production operations have remained significantly more profitable internationally than in U.S. operations. The competition market, which includes corrosion inhibitors, bactericides, viscosities, and defoamers, as well as commodities such as calcium chloride and calcium bromide brines used to maintain well productivity, was estimated at about \$100 million, while the cementing and stimulation segments are about \$2.5 billion.³³

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TABLE 1
SALIENT BROMINE AND BROMINE COMPOUND STATISTICS

(Thousand kilograms unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Bromine sold or used:¹					
Quantity	152,000	163,000	175,000	177,000	170,000
Value	thousands \$107,000	\$144,000	\$188,650	\$173,000	\$167,000
Exports:					
Elemental bromine:					
Quantity	² 3,348	² 4,328	3,557	2,932	2,563
Value	thousands ² \$3,526	² \$3,379	\$3,165	\$4,008	\$7,665
Bromine compounds:³					
Gross weight					
Contained bromine	18,643	11,839	28,998	14,443	14,555
Value	thousands \$18,000	\$13,000	\$24,093	\$18,166	\$21,280
Imports:²					
Elemental bromine:					
Quantity	248	257	460	756	146
Value	thousands \$166	\$194	\$293	\$508	\$199
Compounds:					
Ammonium bromide:					
Gross weight					
Contained bromine	1,830	1,354	1,960	1,245	1,676
Value	thousands \$2,257	\$2,180	\$3,471	\$2,399	\$3,129
Calcium bromide:					
Gross weight					
Contained bromine	2,929	3,427	6,212	9,301	1,243
Value	thousands \$833	\$1,360	\$3,231	\$5,236	\$7,488
Potassium bromate:					
Gross weight					
Contained bromine	665	1,991	1,107	1,003	1,378
Value	thousands \$849	\$1,107	\$3,401	\$3,305	\$7,380
Potassium bromide:					
Gross weight					
Contained bromine	581	569	395	461	595
Value	thousands \$1,122	\$1,278	\$985	\$1,028	\$1,591
Sodium bromide:					
Gross weight					
Contained bromine	510	1,495	1,063	1,266	2,358
Value	thousands \$507	\$1,936	\$1,922	\$2,130	\$3,882
Other:					
Gross weight					
Contained bromine	3,762	14,919	19,787	7,083	8,630
Value	thousands \$13,669	\$35,531	\$42,589	\$50,414	\$47,852
World: Production	391,116	410,922	442,479	416,000	*401,200

¹Estimated.

²Elemental bromine sold as such to nonproducers, including exports, or used in the preparation of bromine compounds by primary U.S. producers.

³Bureau of the Census.

⁴Bureau of the Census. Includes methyl bromine and ethylene dibromide.

**TABLE 2
TIME-PRICE RELATIONSHIPS
FOR BROMINE**

Year	Average annual U.S. producer price, cents per kilogram	
	Actual prices	Based on constant 1991 dollars
1970	38.1	127
1971	38.2	120
1972	36.3	109
1973	35.4	100
1974	60.0	156
1975	61.0	145
1976	49.4	111
1977	47.7	100
1978	46.8	91
1979	48.6	87
1980	54.8	89
1981	48.6	72
1982	59.5	83
1983	59.5	80
1984	74.4	96
1985	74.4	92
1986	74.4	90
1987	77.2	90
1988	98.1	110
1988	98.1	106
1990	98.1	102
1991	123.0	123

**TABLE 3
BROMINE-PRODUCING PLANTS IN THE UNITED STATES IN 1991**

State and company	County	Plant	Production source	Elemental bromine plant capacity ¹ (million kilograms)
Arkansas:				
Arkansas Chemicals Inc.	Union	El Dorado	Well brines	23
Ethyl Corp.	Columbia	Magnolia	do.	50
Do.	do.	do.	do.	73
Great Lakes Chemical Corp.	Union	El Dorado	do.	48
Do.	do.	Marysville	do.	36
Do.	do.	El Dorado	do.	23
Michigan:				
The Dow Chemical Co.	Mason	Ludington	do.	² 9
Total				³ 261

¹Actual production capacity is limited by brine availability.

²Bromine produced at this plant is reprocessed in Arkansas.

³Data do not add to total shown because of independent rounding.

TABLE 4
YEAREND 1991 PRICES FOR ELEMENTAL BROMINE AND
SELECTED COMPOUNDS

Product	Value per pound (cents)	Value per kilogram (cents)
Ammonium bromide, National Formulary (N.F.), granular, drums, carlots, truckloads, f.o.b. works	131	289
Bromine:		
Drums, truckloads, works ¹	123	271
Bulk, tank cars, works ¹	56	123
Bromochloromethane, drums, carloads, f.o.b. Midland, MI	127	280
Calcium bromide, bulk ²	67	148
Ethyl bromide, technical, 98%, drums, truckloads	127	280
Ethylene dibromide, drums, carloads	95	209
Hydrobromic acid, 48%, drums, carloads, truckloads, f.o.b.	42	93
Hydrogen bromide, anhydrous, cylinders, 2,500 pounds, truckloads	475	1,047
Methyl bromide, tank cars	77	170
Potassium bromate, granular, powdered, 200-pound drums, carloads, f.o.b. works	106	234
Potassium bromide, N.F., granular, drums, carloads, f.o.b. works	112	247
Sodium bromide, technical, truckloads	70	154

¹Delivered prices for drums and bulk shipped west of the Rocky Mountains, 1 cent per pound higher. Bulk truck prices 1 to 2.5 cents per pound higher for 30,000-pound minimum and 4 to 5.5 cents per pound higher for 15,000-pound minimum.

²Bureau of the Census. Average c.i.f. import value.

Source: Chemical Marketing Reporter. Current Prices of Chemicals and Related Materials. V. 241, No. 1, Jan. 6, 1992, pp. 23-32.

TABLE 5
U.S. IMPORTS OF OTHER BROMINE COMPOUNDS

Compound	Harmonized schedule code	1990		1991		Principal sources, 1991
		Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)	
Chlorobromodifluormethane	2903400020	5,189.00	\$18,421.00	5,627.00	\$16,103.00	France 15%, Germany 5%, Japan 3%, United Kingdom 75%, other 2%.
Hexabromocyclododecane	2903590500	63.00	344.00	42.00	209.00	France 100%.
Dibromoethyldibromocyclohexane	2903591500	10.00	394.00	66.00	97.00	Germany 72%, Netherlands 24%, United Kingdom 4%.
Ethylenebisbromonorbane	2903595000	1,456.00	4,732.00	3,760.00	4,726.00	Finland 77%, Israel 7%, Japan 9%, Portugal 3%, other 4%.
Pentabromoethylbenzene and tribromocumene	2903692500	110.00	1,129.00	323.00	3,645.00	United Kingdom 100%.
Pentabromoethylbenzene	2903695000	2,534.00	17,649.00	510.00	3,631.00	France 7%, Germany 22%, Italy 36%, Japan 17%, United Kingdom 15%, other 3%.
Dibromoneopentyl glycol	2905505000	451.00	2,817.00	489.00	2,929.00	China 3%, France 17%, Germany 16%, Israel 37%, Norway 7%, United Kingdom 15%, other 5%.
Tetrabromobisphenol A	2908102500	238.00	295.00	129.00	171.00	Israel 75%, Netherlands 23%, other 2%.
Decabromodiphenyl oxide and octabromodiphenyl oxide	2909300700	1,112.00	2,384.00	1,728.00	3,610.00	Israel 96%, United Kingdom 3%, other 1%.

Source: Bureau of the Census.

TABLE 6
BROMINE: WORLD PRODUCTION, BY COUNTRY¹

(Thousand kilograms)

Country ²	1987	1988	1989	1990	1991 ³
France ³	18,500	18,000	18,000	*3,100	3,200
Germany, Federal Republic of:					
Western states ³	2,500	2,500	3,000	3,000	3,000
India	1,182	1,242	1,272	*1,300	1,300
Israel ³	110,000	118,000	135,000	*130,000	130,000
Italy ³	450	450	400	400	400
Japan ³	15,000	15,000	15,000	15,000	15,000
Spain ³	300	300	300	300	300
U.S.S.R. ³	65,000	65,000	65,000	60,000	50,000
United Kingdom	26,184	27,128	29,907	*26,800	28,000
United States ⁴	152,000	163,300	174,600	177,000	*170,000
Total	391,116	410,920	442,479	*416,900	401,200

¹Estimated. ²Revised.

³Table includes data available through Apr. 20, 1992.

⁴In addition to the countries listed, several other nations, notably China and the Eastern states of Germany (the former German Democratic Republic), produce bromine but output data are not reported, and available general information is inadequate for formulation of reliable estimates of output levels.

⁵Reported figure.

TABLE 7
WORLD BROMINE ANNUAL PRODUCTION CAPACITY,¹
DECEMBER 31, 1991, RATED CAPACITY²

(Thousand kilograms)

Country	Capacity
North America: United States	261,000
Europe:	
France	22,000
Germany	6,000
Italy	900
Spain	900
U.S.S.R.	73,000
United Kingdom	30,000
Total ³	133,000
Middle East: Israel	113,000
Asia:	
China	500
India	700
Japan	24,000
Total ³	25,000
World total	532,000

¹Actual capacity limited by brine supply.

²Includes capacity at operating plants as well as at plants on standby basis.

³Data may not add to total shown because of independent rounding.

TABLE 8
WORLD BROMINE ANNUAL PLANT CAPACITIES AND SOURCES¹, DECEMBER 31, 1991

Country and company	Location	Capacity (thousand kilograms)	Source
China:			
Laizhou Bromine Works	Shandong	500	Underground brines.
France:			
Atochem	Port-de-Bouc	13,600	Seawater.
Mines de Potasse d'Alsace S.A.	Mulhouse	8,600	Bitterns of mined potash production.
Germany, Federal Republic of			
Kali und Salz AG: Salzdettfurth Mine	Bad Salzdettfurth	2,500	Do.
Do.	Bleicherode	NA	Do.
Do.	Sondershausen	3,500	Do.
India:			
Hindustan Salts Ltd.	Jaipur		
Mettur Chemicals	Mettur Dam	700	Seawater bitterns from salt production.
Tata Chemicals	Mithapur		
Israel:			
Dead Sea Bromine Co. Ltd.	Sdom	113,000	Bitterns of potash production from surface brines.
Italy:			
Societa Azionaria Industrial Bromo Italiana	Margherita di Savoia	900	Seawater bitterns from salt production.
Japan:			
Asahi Glass Co. Ltd.	Kitakyushu	4,000	Seawater bitterns.
Toyo Soda Manufacturing Co. Ltd.	Tokuyama	20,000	Do.
Spain:			
Derivados del Etilo S.A.	Villaricos	900	Seawater.
U.S.S.R.:			
Government	NA	73,000	Well brines.
United Kingdom:			
Associated Octel Co. Ltd.	Amlwch	30,000	Do.

NA Not available.

¹Excludes U.S. production capacity. See table 3.

CADMIUM

By Thomas O. Llewellyn

Mr. Llewellyn, a physical scientist with over 30 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for cadmium since 1987. Domestic survey data were prepared by Giovanni Jacarepaqua, statistical assistant, Section of Metals Data; and international data were prepared by Ted Spittal, international data assistant, Section of International Data.

Domestic production of cadmium metal in 1991 was at about the same level as that of the previous year, according to the U.S. Bureau of Mines. Four companies operating four plants produced all of the domestic cadmium. The price of cadmium metal declined, continuing a trend that began in mid-1989.

DOMESTIC DATA COVERAGE

Domestic production data for cadmium metal and compounds are developed by the U.S. Bureau of Mines from a voluntary survey of U.S. operations. Of the four metal-producing plants to which a survey request was sent, all responded, representing 100% of the total cadmium metal production shown in tables 1 and 3. Of the 11 operations that produced cadmium compounds to which a survey request was sent, all responded, representing 100% of the cadmium content of production of cadmium compounds shown in table 2. (See tables 1, 2, and 3.)

ANNUAL REVIEW

Legislation and Government Programs

On February 6, 1990, the Occupational Safety and Health Administration (OSHA) published a proposed rule to reduce the existing limit for occupational exposure to airborne cadmium. Public hearings were held, one in Washington, DC, in June and the other in Denver, CO, in July.

The posthearing comment period closed on October 18, 1990.¹ OSHA announced on September 18, 1991, the reopening of the rulemaking record on cadmium for 45 days. The reopening allowed additional information into the record on cadmium sulfide pigments concerning their relative insolubility in biological systems. OSHA also received written comments on those additional comments that were submitted after the posthearing comment period closed and were not publicly discussed.²

On September 24, 1991, the U.S. Department of Commerce notified the public of its determination not to revoke the antidumping on cadmium metal from Japan, as was proposed the month before. Special dumping duties were established in August 1972.³

An updated draft toxicological profile for cadmium published by the Agency for Toxic Substances and Disease Registry, Department of Health and Human Services, was issued in October 1991, and the public comment period will end on February 8, 1992.⁴

Strategic Considerations

Cadmium is included in the National Defense Stockpile (NDS) because of its importance in specialized military applications such as plating where substitutes may be in short supply or unsatisfactory. In addition, the United States depends on imports to meet part of its requirements. Purchase of cadmium under the Strategic and Critical Minerals Stockpiling Act began in 1948, and the

initial stockpile requirements were completed in 1955. Cadmium was also acquired for supplemental stockpile from 1956 through 1963 under provisions of the Agricultural Trade Development and Assistance Act of 1954, which enabled the U.S. Department of Agriculture Commodity Credit Corp. to barter surplus perishable goods for foreign-produced cadmium metal. Government shipments from stockpile excesses for 1964-76 totaled 3,918 tons. In April 1980, the stockpile goal for cadmium was set at 5,307 metric tons. At the end of 1991, the NDS cadmium inventory was 2,871 metric tons.

Production

Primary cadmium was produced by ASARCO Incorporated, Denver, CO; Big River Zinc Corp., Sauget, IL; Jersey Miniere Zinc Co., Clarksville, TN; and Zinc Corp. of America, Bartlesville, OK. The companies in Illinois, Oklahoma, and Tennessee recovered cadmium as a byproduct of smelting domestic and imported zinc concentrates. The company in Colorado recovered cadmium from other sources such as lead smelter baghouse dust.

Consumption and Uses

Apparent consumption of cadmium increased compared with that of 1990. Although the U.S. Bureau of Mines does not collect actual consumption data, apparent consumption by use categories in

1991 was estimated as follows: batteries, 45%; coating and plating, 20%; pigments, 16%; plastic and synthetic products, 12%; and alloys and other, 7%.

Stocks

Total inventories of cadmium metal and cadmium compounds increased about 71% and 26%, respectively, compared with those of 1990. (See table 4.)

Markets and Prices

The New York dealer price range for cadmium metal, published by Metals Week, at the beginning of 1991 was \$3.00 to \$3.22 per pound, about 40% less than the price range quoted at the beginning of 1990. The prices for cadmium metal fluctuated slightly during the first 6 months of the year, but followed a downward trend and reached a low range of \$1.50 to \$1.60 per pound by June 6, 1991. However, during the next 3 months the cadmium market showed signs of recovery, and the price range at the end of October was \$1.90 to \$2.05 per pound; this price range prevailed through yearend. The price decline was due to a lower market demand for end uses of cadmium such as coating and plating, and alloys and other.

Foreign Trade

Cadmium is taxed under the Superfund Amendments and Reauthorization Act of 1986, Public Law 99-499. The tax, to be collected from producers and importers, was \$4.45 per ton of cadmium metal. The tax, which was scheduled to expire on December 31, 1991, has been rescheduled to end on December 31, 1995. Cadmium producers are granted a depletion allowance of 22% on domestic production and 14% on foreign production.

Under the new Harmonized Tariff Schedule of the United States, which took effect January 1, 1989, cadmium sulfide and pigments and preparations based on cadmium compounds imports from most favored nations (MFN) are subject to a 3.1% ad valorem duty; for non-MFN a

25% ad valorem duty was retained. Imports of unwrought cadmium, waste and scrap, and powders, are duty free for MFN, whereas a statutory duty of 33 cents per kilogram was imposed on these materials for non-MFN. (See tables 5 and 6.)

World Review

Industry Structure.—World refinery production of cadmium was estimated at 20,673 metric tons in 1991. Japan was the largest producer of refined cadmium in 1991, followed by the U.S.S.R., Belgium, the United States, Canada, China, and Germany. These seven countries accounted for approximately 61% of the world's refined cadmium production in 1991. Because cadmium is recovered mainly as a byproduct of zinc ore processing, many producers of zinc and zinc compounds produce primary cadmium as an integral part of their operation. In some cases, residues and flue dusts from zinc producers are used directly by cadmium producers. Some cadmium may also be recovered from flue dust generated at various lead and copper smelters; however, the amount of this production is not known.

Capacity.—The data in table 7 represent rated annual production capacity for mines and refineries on December 31, 1991. Rated capacity was defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable, long-term operating rate, based on the physical equipment of the plant and routine operating procedures for labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. (See tables 7 and 8.)

Reserves.—Cadmium reserves were obtained by applying an average recovery factor of 0.36% to zinc reserve data. On this basis, the domestic reserves of cadmium were estimated at 72,000 metric

tons. Total world reserves were estimated to be about 535,000 metric tons. The world's largest reserves of cadmium were in the United States and Canada.

Cadmium minerals are not found in commercial viable deposits, and its abundance in the Earth's crust is about 0.2 parts per million. Greenockite (CdS) is the only cadmium mineral of importance; it is not found in any isolated deposit, but is nearly always associated with zinc sulfide. Cadmium is usually produced as a byproduct in the recovery of primary zinc from zinc ores and also from some lead ores or complex copper-lead-zinc ores. However, it is generally agreed that the cadmium in lead and copper ores is associated with the zinc sulfide present rather than with the other minerals.

Current Research

The U.S. Bureau of Mines investigated hydrometallurgical processing techniques to recycle metals from semiconductors and other advanced materials. Cadmium and tellurium were recovered from cadmium telluride (CdTe) scrap produced in the manufacturing of both infrared optic devices and thin-film photovoltaic devices. Leaching the crushed CdTe infrared optic scrap for 75 minutes at 110° C in dilute sulfuric acid under 120 psig oxygen yielded 99.5% cadmium extraction. Tellurium remained in the leach residue as tellurium oxide and elemental tellurium. The cadmium in the leach liquor was purified of coextracted metals such as gallium and iron by adjusting the pH to 5.3. The cadmium was recovered as cadmium sulfate crystals by evaporating the solution.⁵

Bacteria operate on metals through bioleaching, biosorption, and bioreduction mechanisms. Based on these mechanisms, the U.S. Bureau of Mines developed a promising technique to extract metal contaminants from wastewaters using porous polymeric beads containing nonliving biological materials. Biomass materials used in the beads included algae, duckweed, sphagnum moss, and yeast.

Batch and continuous tests demonstrated that beads selectively remove metal contaminants, such as cadmium, mercury, copper, lead, and zinc, from a variety of wastewaters. Treated effluents often met the federally established National Drinking Water Standards.⁶ The Environmental Protection Agency established an interim Maximum Contamination Level (MCL) of 10 micrograms per liter for cadmium in drinking water.

Developments in cadmium technology during the year were abstracted in *Cadscam*, a quarterly publication available through the Cadmium Association, 42 Weymouth Street, London, WIN 3LQ, England.

OUTLOOK

The short-term demand for cadmium in the United States was expected to fall below the level of 1990. This decline was expected to be the result of continuing lower demand for cadmium in coating and plating and pigments during the next 2 to 4 years. There was a strong indication that the world demand for primary cadmium will follow the same trend, for the reasons aforementioned, which are a consequence of stricter environmental and health controls now under consideration in North America and Europe.

¹Federal Register. Occupational Exposure to Cadmium; Proposed Rule. V. 55, No. 25, Feb. 6, 1990, pp. 4052-4147.

²Occupational Exposure to Cadmium; Notice of Limited Reopening of Rulemaking Record. V. 56, No. 181, Sept. 18, 1991, pp. 47348-47349.

³Cadmium From Japan; Determination Not To Revoke Antidumping Finding. V. 56, No. 185, Sept. 24, 1991, p. 48157.

⁴Availability of Draft Toxicological Profiles. V. 56, No. 201, Oct. 17, 1991, pp. 52036.

⁵Tolley, W. K., and G. R. Palmer. Recovering Cadmium and Tellurium From CdT Manufacturing Scrap. Ch. in EPD Congress 91, ed. by D. R. Gaskell. The Miner., Met., and Mater., Soc., Warrendale, PA, 1991, pp. 209-218.

⁶Jeffers, T. H., C. R. Ferguson, and P. G. Bennett. Biosorption of Metal Contaminants Using Immobilized Biomass—A Laboratory Study. BuMines RI 9340, 1991, 9 pp.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Cadmium. Ch. in Mineral Commodity Summaries, annual.

Cadmium. Ch. in Mineral Facts and Problems, 1985 ed.

Other Sources

American Metal Market.

Chemical Abstracts.

Engineering and Mining Journal.

Mining Journal (London).

TABLE 1
SALIENT CADMIUM STATISTICS

		1987	1988	1989	1990	1991
United States:						
Production ¹	metric tons	1,515	1,885	1,550	1,678	1,676
Shipments by producers ²	do.	1,916	2,074	2,015	1,855	1,736
Value	thousands	\$1,861	\$5,389	\$2,282	\$3,567	\$3,234
Exports	metric tons	241	613	369	385	158
Imports for consumption, metal	do.	2,701	2,482	2,787	1,741	2,039
Apparent consumption	do.	4,178	3,620	4,096	3,107	3,238
Price, average per pound, in 1 to 5 short ton lots: New York dealer		\$1.60	\$6.91	\$6.28	\$3.38	\$2.01
World: Refinery production	metric tons	19,169	21,761	21,325	20,493	20,673

¹Estimated. ²Revised.

¹Primary and secondary cadmium metal. Includes equivalent metal content of cadmium sponge used directly in production of compounds.

²Includes metal consumed at producer plants.

TABLE 2
U.S. PRODUCTION OF
CADMIUM COMPOUNDS

(Metric tons, cadmium content)

Year	Cadmium sulfide ¹	Other cadmium compounds ²
1987	540	1,511
1988	345	1,497
1989	267	1,451
1990	228	1,144
1991	329	1,089

¹Includes cadmium lithopone and cadmium sulfoelenide.

²Includes plating salts and oxide.

TABLE 3
SUPPLY AND APPARENT
CONSUMPTION OF CADMIUM

(Metric tons)

	1989	1990	1991
Stocks, January 1	854	726	653
Production	1,550	1,678	1,676
Imports for consumption, metal	2,787	1,741	2,039
Total supply	5,191	4,145	4,368
Exports	369	385	158
Stocks, December 31	726	653	972
Consumption, apparent ¹	4,096	3,107	3,238

¹Total supply minus exports and yearend stocks.

TABLE 4
INDUSTRY STOCKS, DECEMBER 31

(Metric tons)

	1990		1991	
	Cadmium metal	Cadmium in compounds	Cadmium metal	Cadmium in compounds
Metal producers	221	W	463	W
Compound manufacturers	107	316	68	397
Distributors	8	1	43	1
Total	336	317	574	398

W Withheld to avoid disclosing company proprietary data; included with "Compound manufacturers."

TABLE 5
U.S. EXPORTS OF CADMIUM
METAL AND CADMIUM IN
ALLOYS, DROSS, FLUE DUST,
RESIDUES, AND SCRAP

Year	Quantity (metric tons)	Value (thousands)
1989	369	\$857
1990	385	1,174
1991	158	218

Source: Bureau of the Census.

TABLE 6
U.S. IMPORTS FOR CONSUMPTION¹ OF CADMIUM METAL, BY COUNTRY

Country	1989		1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Argentina	—	—	—	—	27	\$105
Australia	173	\$2,391	199	\$1,272	221	1,015
Belgium	120	1,045	37	288	20	65
Brazil	22	328	—	—	47	136
Canada	947	11,042	743	5,402	750	3,130
China	40	840	17	171	4	8
Finland	3	46	2	21	—	—
France	333	1,522	29	249	72	288
Germany, Federal Republic of	139	1,837	71	615	201	676
Greece	—	—	—	—	38	116
Italy	(?)	2	—	—	40	123
Japan	2	48	(?)	31	(?)	22

See footnotes at end of table.

TABLE 6—Continued
U.S. IMPORTS FOR CONSUMPTION¹ OF CADMIUM METAL, BY COUNTRY

Country	1989		1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Korea, Republic of	21	\$334	—	—	1	\$2
Mexico	616	7,525	345	\$1,926	352	1,178
Namibia	24	337	—	—	—	—
Netherlands	132	559	59	448	40	145
Norway	35	415	85	589	113	464
Peru	59	755	27	95	41	152
Spain	17	192	22	195	47	210
Switzerland	12	190	—	—	—	—
Taiwan	41	229	22	185	—	—
United Kingdom	46	470	83	417	10	53
Venezuela	(²)	4	—	—	5	12
Yugoslavia	5	49	—	—	—	—
Zaire	—	—	—	—	10	28
Total	2,787	³30,161	1,741	11,904	2,039	7,928

¹General imports and imports for consumption were the same in 1989, 1990, and 1991.

²Less than 1/2 unit.

³Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 7
**WORLD ANNUAL CADMIUM
 PRODUCTION CAPACITY,
 DECEMBER 31, 1991**

(Metric tons, cadmium content)

	Mine	Refinery
North America:		
Canada	4,500	2,500
Mexico	2,000	1,400
United States	2,000	3,100
Total	8,500	7,000
Central America	300	—
South America:		
Peru	1,500	500
Other	700	200
Total	2,200	700
Europe	7,500	10,500
Africa	1,000	600
Asia:		
Japan	600	5,000
Other	2,400	1,200
Total	3,000	6,200
Oceania:		
Australia	2,300	1,100
World total	24,800	26,100

TABLE 8
CADMIUM: WORLD REFINERY PRODUCTION,¹ BY COUNTRY

(Metric tons)

Country	1987	1988	1989	1990	1991*
Algeria	102	55	¹ 46	¹ 65	65
Argentina	46	46	¹ 54	¹ 48	50
Australia	944	855	696	¹ 638	800
Austria	26	26	49	¹ 44	² 22
Belgium	1,308	1,836	1,761	¹ 1,956	1,800
Brazil	214	161	197	² 200	200
Bulgaria*	² 250	³ 300	³ 350	¹ 2309	300
Canada	¹ 1,571	¹ 1,694	1,620	1,437	1,400
China*	680	750	800	¹ 1,000	1,200
Finland	690	703	612	¹ 568	² 593
France	457	558	790	¹ 780	700
Germany, Federal Republic of:					
Eastern states*	18	³ 30	² 26	¹ 17	NA
Western states	1,125	1,159	1,208	¹ 973	NA
Total*	1,143	¹ 1,189	¹ 1,234	¹ 990	1,105
India	214	237	275	² 277	280
Italy	320	705	¹ 770	¹ 665	² 734
Japan	2,450	2,614	2,694	² 2,451	² 2,889
Korea, North*	100	100	100	100	100
Korea, Republic of	—	490	¹ 500	¹ 500	450
Mexico	935	1,117	976	¹ 882	900
Namibia	51	106	88	75	75
Netherlands	517	¹ 563	¹ 505	¹ 590	² 549
Norway	147	169	² 206	² 286	² 236
Peru	³ 351	³ 303	³ 352	² 265	350
Poland	¹ 620	¹ 642	¹ 485	³ 373	350
Romania*	75	75	70	62	60
South Africa, Republic of	33	37	¹ 40	¹ 40	40
Spain	297	438	361	³ 355	350
Turkey	11	22	¹ 54	¹ 46	50
U.S.S.R.*	3,000	3,000	3,000	2,800	2,500
United Kingdom	498	399	395	¹ 438	² 449
United States ³	1,515	1,885	1,550	1,678	² 1,676
Yugoslavia	305	405	¹ 471	¹ 362	280
Zaire	299	281	224	¹ 213	120
Total	¹ 19,169	² 21,761	² 21,325	² 20,493	20,673

*Estimated. ¹Revised. NA Not available.

²This table gives unwrought production from ores, concentrates, flue dusts, and other materials of both domestic and imported origin. Sources generally do not indicate if secondary metal (recovered from scrap) is included or not; where known, this has been indicated by a footnote. Data derived in part from World Metal Statistics (published by World Bureau of Metal Statistics, Ware, United Kingdom) and from Metal Statistics (published by Metallgesellschaft Aktiengesellschaft, Frankfurt am Main, Germany). Cadmium is found in ores, concentrates, and/or flue dusts in several other countries, but these materials are exported for treatment elsewhere to recover cadmium metal; therefore, such output is not reported in this table to avoid double counting. This table includes data available through Apr. 2, 1992.

³Reported figure.

⁴Includes secondary.

CALCIUM AND CALCIUM COMPOUNDS

By M. Michael Miller

Mr. Miller, a physical scientist with 14 years of minerals experience with the U.S. Department of the Interior, has been the commodity specialist for calcium and calcium compounds since 1989. Domestic survey data were prepared by Joseph C. Daniels, statistical assistant. All units are in metric tons, unless otherwise noted.

Calcium, the fifth most abundant element in the Earth's crust, is chemically very active and is found in a host of minerals that occur in nearly every geologic environment. The U.S. Bureau of Mines publishes reports for a variety of calcium-containing minerals and compounds because of their commercial significance and contribution to the quality of human life. Calcium fluoride is sold as fluorspar; calcium sulfate as gypsum or anhydrite; calcium oxide and hydroxide as lime; calcium phosphate as phosphate rock; and natural calcium carbonate as either limestone, marble, calcareous marl, or shell. Information on these commodities can be obtained in the U.S. Bureau of Mines annual reports entitled, "Fluorspar," "Gypsum," "Lime," "Phosphate Rock," "Crushed Stone," and "Dimension Stone." Other calcium compounds are discussed in the report concerning the element with which calcium is combined; for example, calcium bromide is covered in the "Bromine Annual Report." This "Calcium and Calcium Compounds Annual Report" includes calcium metal, calcium chloride, precipitated calcium carbonate, and various other calcium compounds not covered elsewhere.

DOMESTIC DATA COVERAGE

The U.S. Bureau of Mines develops domestic production data for calcium chloride from a voluntary survey of U.S. operations entitled, "Calcium Chloride and Calcium-Magnesium Chloride." Of the seven operations polled, all responded, representing about 21% of the total production shown in table 1.

Production for two producers not polled was estimated using data from previous years, published plant capacity, and contacts within the industry. (See table 1.)

BACKGROUND

Grades and Specifications

Calcium metal is usually sold in the form of crowns, broken crown pieces or nodules, or billets, which are produced by melting crowns in an argon atmosphere. The metal purity in these forms is at least 98%. Higher purity metal is obtained by redistillation. Calcium metal is usually shipped in polyethylene bags under argon in airtight steel drums. Table 2 shows typical specifications for commercial grade, melted grade, and redistilled grade. (See table 2.)

The American Society for Testing and Materials (ASTM) issues a standard specification for calcium chloride designated D 98. It covers technical-grade calcium chloride to be used for road conditioning purposes, ice removal, concrete curing, acceleration of the set of concrete, and as a desiccant. D 98 covers two types of calcium chloride, solid (Type S) and liquid (Type L). Solid occurs in flake, pellet, granular, and powder form in concentrations of 77%, 90%, and 94% minimum. Liquid occurs as water solutions of calcium chloride in concentrations varying from 30% to 45%. Calcium chloride is divided into three grades: Grade 1—77% minimum, Grade 2—90% minimum, and Grade 3—94% minimum. Within each grade there are

sieve-size requirements for flake, pellet, granular, and powder forms.¹

Technology

Calcium Metal.²—In 1808, Davy produced elemental calcium as a mercury amalgam by the electrolysis of calcium chloride in the presence of a mercury cathode. He and others were only marginally successful in attempts to isolate the pure metal by distilling the mercury. In 1855, Bunsen and Matthiessen attempted to produce calcium metal by the electrolysis of a mixture of calcium, strontium, and ammonium chlorides to lower the electrolyte melting point, but produced only finely divided calcium alloys. This process was slowly improved, and by 1904, Rathenau obtained calcium by the electrolysis of molten calcium chloride held at a temperature above the melting point of the salt but below the melting point of calcium metal. An iron cathode just touched the surface of the bath and was raised slowly as the relatively chloride-free calcium deposited on its end. This process accounted for virtually all calcium metal production from 1904 to 1940.

Prior to 1939, calcium was manufactured exclusively in France and Germany. With the outbreak of World War II, an electrolytic calcium plant was constructed at Sault Ste. Marie, MI, by the Electro Metallurgical Corp. Large quantities of calcium were required as the reducing agent for uranium production. In addition, the U.S. Army Signal Corps used calcium to produce calcium hydride, which could easily be transported to

remote areas and used as a source of hydrogen for meteorological balloons. To satisfy these needs, an aluminothermic reduction process was developed. Developed earlier on a laboratory scale in 1922, the process was improved and commercialized by the New England Lime Co. in Canaan, CT, which later became a division of Pfizer Inc.

The aluminothermic process, or Pidgeon process as it is sometimes called, begins with quarried high-calcium limestone calcined to form calcium oxide. The calcium oxide is ground to a small particle size and dry-blended with finely divided aluminum. The mixture is compacted into briquets to ensure good contact of reactants. The briquets are placed in horizontal metal tubes, called retorts, made of heat-resistant steel and heated in a furnace to 1,100° C to 1,200° C under high vacuum, and the calcium oxide is reduced to calcium metal. The calcium metal vapor is collected in the water-cooled condenser section of the retort at about 700° C. After the reaction has proceeded for about 24 hours, the vacuum is broken with argon, and the condensed blocks of 98%-pure calcium metal, called "crowns," and the calcium aluminate reaction product are removed.

For certain applications greater than 98% purity is required, which is achieved by redistillation. Crude calcium is placed in the bottom of a large vertical retort equipped with a water-cooled condenser at the top. The retort is sealed and evacuated to a pressure of less than 6.6 pascal (0.05 millimeters of mercury), while the bottom is heated to 900° C to 925° C. The calcium quickly distills into the condensing section, leaving behind the bulk of the less volatile impurities. Subsequent processing must take place under exclusion of moisture to avoid oxidation. Redistillation does not greatly reduce the impurity level of volatile materials such as magnesium.

Calcium Chloride.³—Domestic calcium chloride is produced from natural brines and by reacting hydrochloric acid with limestone. Most U.S. production is natural from brine wells in Michigan,

with a small amount from dry lake beds in California.

Initial efforts to stimulate the development of Michigan salt and brine deposits took place in 1859. The State legislature passed a bill authorizing payment for Michigan salt. By 1870, saw mill operators were augmenting their income by using waste lumber as fuel to evaporate brines. In 1882, solution mining of rock salt began, and Michigan soon became the leading salt-producing State.

By 1914, an integrated process was developed using three vacuum evaporators to extract various brine components. Bromine was extracted first in an electrolytic cell, and the debrominated brine was then processed through a heated vacuum evaporator. This process precipitated sodium chloride, which was used to produce chlorine, hydrogen, and sodium hydroxide. The brine was then sent to a second evaporator where magnesium chloride was precipitated out. The brine from the second evaporator went to a third evaporator, which produced precipitated hydrates of calcium chloride and a 38% calcium chloride product.

Today the process has been expanded and improved to extract, in sequence, iodine, bromine, magnesium chloride, and calcium chloride. The calcium chloride is derived from the brine left over after processing the magnesium chloride into magnesium hydroxide. This brine is about 25% calcium chloride, and it is processed through double- or triple-effect vacuum evaporators to make a 32% to 45% solution. Unwanted alkali chlorides are precipitated here and can be removed by settlers and centrifuges. The brine undergoes further evaporation to attain an anhydrous product of 78% to 94% calcium chloride concentration.

Precipitated Calcium Carbonate.⁴—Calcium carbonate occurs in two crystalline forms—aragonite and calcite. These forms possess different physical properties. There are three basic processes for the manufacture of calcium carbonate as a precipitate. The processes include the lime-soda process, the lime-

ammonium chloride process, and the carbonation process. All three start with a dilute lime hydrate in aqueous suspension, descriptively called milk-of-lime.

In the lime-soda process, milk-of-lime is reacted with sodium carbonate to produce calcium carbonate and sodium hydroxide. The commercial alkali manufacturers used this process, which produced as a byproduct a coarse calcium carbonate precipitate. Production of a uniform, fine-particle-size precipitate could only be achieved at the expense of the primary goal, caustic soda recovery.

In the lime-ammonium chloride process, milk-of-lime is reacted with ammonium chloride to produce calcium chloride. The calcium chloride is purified and then reacted with soda ash to form calcium carbonate. The process can be fine tuned by modifying the addition times, method and rate of agitation, pH, concentrations, and reaction temperatures. This process requires a low-cost source of sodium carbonate and calcium chloride, and production, historically, has been as a satellite to Solvay process synthetic soda ash plants. The last domestic synthetic soda ash plant closed in 1986.

The most common production process used in the United States is the carbonation process. Carbon dioxide is bubbled through milk-of-lime to form a precipitate of calcium carbonate and water. The reaction conditions determine the particle size and shape of the resulting aragonite or calcite. To modify the dimensions and performance characteristics of the precipitate, it is necessary to adjust a range of variables that include concentration, starting temperature, pH, degree and type of mixing, solution rates, and the addition of additives. Calcite, aragonite, or a mixture of both can be produced, although commercial forms are usually exclusively one form or the other. The carbonation process is the most complex of the three processes. Because of the low cost availability of raw materials, it has become the process of choice and forms the foundation of the expanding network of satellite precipitated calcium carbonate plants adjacent to pulp and paper mills.

ANNUAL REVIEW

Strategic Considerations

Redistilled-grade calcium metal was used to reduce uranium dioxide, a fuel in some types of fission reactors. The nuclear applications of calcium metal gave it strategic significance; the U.S. Department of State would not permit sales to countries not signatory to the United Nations Nuclear Nonproliferation Treaty.

Production

Pfizer Inc. produced calcium metal at Canaan, CT, by the Pidgeon process, in which high-purity calcium oxide (produced by calcining limestone) and aluminum powder are compacted into briquets and heated in vacuum retorts. The vaporized calcium metal product collects as a "crown" in a water-cooled condenser. Production was up slightly compared with that of 1990.

Pfizer produced commercial-grade 98.5% calcium in eight shapes and high-purity redistilled 99.2% metal in three shapes, with other shapes available on request. They produced an 80% to 20% calcium-magnesium alloy, a pure calcium wire used in the steel industry to modify inclusions, and a 73% to 27% calcium-aluminum alloy or unalloyed calcium-aluminum briquette. Elkem Metals Co., a Norwegian-owned company with headquarters in Pittsburgh, PA, produced a calcium-silicon-barium-aluminum alloy at its plant in Niagara Falls, NY, and imported several other calcium alloys.

Michigan was the leading State in natural calcium chloride production; California was a distant second. The Dow Chemical Co. and Wilkinson Corp. (formerly Wilkinson Chemical Corp.) recovered calcium chloride from brines in Mason and Lapeer Counties, MI. Dow's Ludington plant produced calcium chloride pellets, flake, and liquid; Wilkinson marketed calcium chloride solutions only. National Chloride Co. of America, Cargill's Leslie Salt Co., and Hill Brothers Chemical Co. produced

calcium chloride from dry-lake brine wells in San Bernadino County, CA. Hill Brothers Chemical also produced from a second operation near Cadiz Lake, CA, and marketed material produced by Magnesium Corp. of America as a byproduct of magnesium production in Rowley, UT.

Tetra Chemicals produced synthetic calcium chloride from a plant near Lake Charles, LA, and from its liquids plant at Norco, LA. Allied Signal Inc. recovered calcium chloride as a byproduct at its Baton Rouge, LA, plant using hydrochloric acid and limestone. Occidental Chemical Corp. manufactured calcium chloride at Tacoma, WA, using limestone and hydrochloric acid. Standard Chlorine of Delaware discontinued production of synthetic calcium chloride in 1991.

At the end of 1991, there were 26 precipitated calcium carbonate (PCC) plants operating in the United States. Pfizer Inc. had 17 satellite PCC plants in operation in the United States plus 2 additional plants in Canada and 1 in Japan. English China Clay International (ECCI) operated three satellite plants in the United States and one in Canada in 1991. The ECCI plants operated in 1990 under the name GK Carbonate. There are reportedly three additional companies operating satellite PCC plants. There are three companies that produce PCC for the open market: Pfizer Inc. at Adams, MA, Mississippi Lime Co. at Ste. Genevieve, MO, and Continental Lime Inc. at Tacoma, WA. The 26 U.S. plants have an estimated capacity in excess of 1 million tons.

Calcium hypochlorite was produced by Olin Corp. at Charleston, TN, and PPG Industries Inc. at Natrium, WV. Sales were relatively unchanged from those of 1990. Total domestic calcium hypochlorite capacity was 106,000 tons. In early 1991, Olin Corp. started production from a new 9,000-ton-per-year plant in Charleston, TN.

Consumption and Uses

Calcium metal was used in the manufacture of maintenance-free and

sealed lead-acid batteries, as an aid in removing bismuth in lead refining, and as a desulfurizer and deoxidizer in steel refining. It was used to reduce oxides of the rare earth neodymium and boron for alloying with metallic iron for use in neodymium-iron-boron permanent magnets. It was used as a reducing agent to recover many of the less common metals such as hafnium, plutonium, thorium, tungsten, uranium, and vanadium and the rare earths from their oxides or fluorides. Some minor uses were in the preparation of vitamin B and chelated calcium supplements and as a cathode coating in some types of photoelectric tubes. Domestic consumption of calcium metal increased in 1991. This was evidenced by increased imports reported by the Bureau of the Census, U.S. Department of Commerce.

Calcium chloride was used to deice pavements, to control dust, to stabilize road bases, to thaw coal and other bulk materials, in oil and gas drilling, for concrete-set acceleration, as tire ballasting, to deink newspaper, and in miscellaneous other uses. The principal use of calcium chloride was to melt snow and ice from roads. Calcium chloride is more effective at lower temperatures than rock salt and was used mainly in the Northern and Eastern States. Because of its considerably higher price, it was used in conjunction with rock salt for maximum effectiveness and economy.

Precipitated calcium carbonate was used as a pigment for brightness and opaqueness in premium-quality coated papers and as a filler in uncoated papers. In coated paper, PCC was used in the coating to improve paper brightness and print clarity. In uncoated papers, it was used as a filler and extender in the paper to improve the optical, physical, and price-performance characteristics of the paper. The plastics industry used a fine and ultrafine grade of PCC to lower raw material costs, increase impact resistance, improve surface smoothness, and enhance color stability. Its major use was in polyvinyl chloride (PVC), but it was also used in such polymers as polystyrene, polypropylene, and polyethylene. The paint industry used it as a replacement for

expensive TiO₂ pigment and to control flow properties, provide body, and maintain dispersion.⁵

Calcium hypochlorite was used to disinfect swimming pools, which accounted for more than 85% of domestic demand. Municipal sanitation and industrial bleaching accounted for the remainder. It was used as an algicide, bactericide, deodorant, water purifier, disinfectant, fungicide, and bleaching agent.

Calcium nitrate was used as a concrete additive to inhibit corrosion of steel reinforcement bars, accelerate setting time, and enhance strength.

Calcium carbide and calcium-silicon alloy were used to remove sulfur from molten pig iron as it was carried in transfer ladles from the blast furnace to the steelmaking furnace.

Prices

The published price of calcium metal last changed April 19, 1990, according to the Metal Bulletin. The yearend published price range for calcium metal, minimum 98%, was \$2.25 to \$2.75 per pound, U.S. free market.⁶ This was equivalent to \$4.96 to \$6.06 per kilogram. The published price did not change in 1991. Calcium metal is sold on a contract basis, and the contract price may vary greatly from the published price. The published price range only serves as a guide to the prices obtained by dealers and producers.

Solid calcium chloride prices were quoted by Chemical Marketing Reporter for Grade 1 (minimum 77%) and Grade 3 (minimum 94%), generally in flake or pellet form. Liquid prices were quoted for a range of 30% to 42% concentration and for 45% concentration. Although actual prices are negotiated and usually discounted, yearend 1991 published prices and specifications are shown in table 3.

Precipitated calcium carbonate prices as reported by Chemical Marketing Reporter did not change in 1991. List prices for technical grade, (0.5 microns), bags, bulk, f.o.b. works, were \$212.00 per short ton (about \$234.00 per metric ton). List prices for ultrafine, (0.05 to 0.5

microns), bags, bulk, f.o.b. works, were \$540.00 per short ton (about \$595.00 per metric ton). List prices for surface treated, bags, bulk, f.o.b. works, were \$320.00 per short ton (about \$353.00 per metric ton).⁷ (See table 3.)

Foreign Trade

U.S. exports of calcium chloride increased by 31% in 1991, with a substantial portion of the increase going to Canada. The United States exported 31,306 tons of calcium hypochlorite to many countries for an export value of about \$33,796,000. More than 9,703 tons of calcium carbide was exported to 17 countries for an export value of more than \$5,299,000. Exports of 3,716 tons of calcium cyanamide went predominantly to Mexico. (See table 4.)

Imports of calcium metal increased by more than 26% compared with those of 1990. The majority of shipments came directly from China, France, and Canada, in descending order. According to Bureau of the Census import data, the average c.i.f. unit value of imported calcium metal was \$6.38 per kilogram (\$2.89 per pound), which exceeded the published price range. There was a tremendous disparity between the value of material from China and the U.S.S.R. and the value of material from Canada and France. The material from Canada and France included calcium alloys and powdered or granulated calcium. (See tables 5, 6, and 7.)

OUTLOOK

The major end uses of calcium metal are in the lead industry primarily in maintenance-free and sealed lead-acid batteries; in the steel industry; and as a reducing agent of rare-earth oxides for permanent magnet manufacture. These three areas each account for roughly one-third of domestic calcium metal consumption.

The majority of the maintenance-free and sealed lead-acid batteries go into the U.S. starter battery market primarily as replacement batteries for automobiles. The replacement battery market is

weather dependent, as temperature extremes tend to damage batteries. Owing to the recession and the mild winter in 1991, calcium metal consumption decreased in this market. Based on projections made for the battery industry and assuming no growth in overall lead consumption and the continuation of sluggish economic conditions, it is estimated that consumption will be flat in 1992. Beyond 1992, calcium metal consumption in this market segment is expected to grow by 2% to 3% annually through 1994.

Despite the 13% decrease in raw steel production in 1991, calcium metal consumption for steel refining was strong. This market is expected to remain strong in 1992 and beyond. This optimism is based on the increased efficiencies achieved by using calcium.

Calcium metal's use as a reducing agent of rare-earth oxides for permanent magnet manufacture was a strong market in 1991. Consumption in this area should increase during the next few years due to an expanding permanent magnet market.

Calcium chloride consumption is still very dependent on the vagaries of the weather. The mild winter in 1991 hurt the deicing market, which was also the case in 1990. The deicing, dust control, and road stabilization markets are dependent on the weather. These markets are mature, and consumption levels should be flat except for fluctuations caused by year-to-year changes in precipitation levels. A decline in oil drilling activity has slowed expected growth in the drilling fluids market. Calcium chloride is added to specially designed oil muds to deal with plastic flowing shale encountered offshore Louisiana, in Wyoming, and in other locations. Passage of the Intermodal Transportation Efficiency Act and a pickup in the construction industry should boost the market for its use as a concrete-set accelerator. A niche market that should grow is newsprint deinking. Some industry sources believe that a future growth market is in the agricultural sector, where it would be used as a growth enhancing macronutrient.

There is already an excess of capacity in the calcium chloride industry. This excess capacity is likely to become more acute as additional synthetic or byproduct capacity comes on-line in the next few years. Calcium chloride production utilizing hydrochloric acid is seen as a solution to an oversupply of hydrochloric acid and the need for deep well disposal. In addition, Dow Chemical Co. is considering converting its propylene oxide manufacturing process from the use of caustic soda to the use of hydrated lime. If the conversion is made, the new process could generate approximately 225,000 tons of byproduct calcium chloride.

The outlook for precipitated calcium carbonate consumption continues to be driven by the pace of conversions to alkaline sizing by the paper industry. The North American market has the potential for 35 to 40 satellite plants. Construction of satellite plants slowed down in 1991; only a few were built. Pfizer has an additional 13 plants under construction or planned for North America and overseas. Demand for both ground and precipitated calcium carbonate fillers is expected to grow at a rate of 10% per year.

The many benefits of PCC use by the paper industry have recently been balanced by criticism that, as paper filler levels increase, PCC performance will deteriorate because of poor drainage and increased water retention. Pfizer, which has reinvested much of its PCC profits into research and development, is continuing to work on new product development and is currently field testing new products with increased filler-loading levels.

Although most paper markets slowed down during 1991, long-term growth is expected when the economy turns around. Because paper accounts for the largest portion of PCC consumption, this growth will be reflected by increased PCC sales. The outlook for PCC consumption in paints and plastics is tied to the health of the economy, the construction industry, and the automobile industry. Both markets are expected to be flat through

most of 1992 and then grow when the economy recovers.

¹American Society for Testing and Materials. 1988 Annual Book of ASTM Standards. V. 4.03, 1988, pp. 88-90.

²Kunesh, C. Calcium and Calcium Alloys. Sec. in Kirk-Othmer: Encyclopedia of Chemical Technology, v. 4. John Wiley & Sons, 3d ed., 1978, pp. 412-421.

³Pavlick, J. Chemicals From Michigan Brines. Soc. Min. Eng. AIME preprint 84-385, 1984, 10 pp.

⁴Hagemeyer, R. W. (ed.). Pigments for Paper. Tappi Press, 1987, pp. 53-67.

⁵Hagemeyer, R. W. Precipitated Calcium Carbonate—Fillers for Paint, Paper and Elastomers. Soc. Min. Eng. AIME preprint 89-22, 1989, 14 pp.

⁶Metal Bulletin (London). No. 7644, Dec. 30, 1991, p. 22.

⁷Chemical Marketing Reporter. V. 240, No. 27, Dec. 30, 1991, p. 23.

OTHER SOURCES OF INFORMATION

Chemical Marketing Reporter. Chemical Profile, Calcium Chloride. V. 237, No. 26, June 25, 1990, p. 50.

Mannsville Chemical Products Corp. Calcium Chloride. Chemical Products Synopsis (Asbury Park, NJ), Mar. 1989, 2 pp.

Roskill Information Services Ltd. The Economics of Calcium Metal. 4th ed. (London), 1990, 72 pp.

TABLE 1
SALIENT CALCIUM CHLORIDE STATISTICS¹

(Metric tons unless otherwise specified)

	1987	1988	1989	1990	1991
Number of operations	10	10	10	9	9
Production ²	597,000	663,000	727,000	626,000	584,000
Value ²	\$87,400	\$86,700	\$113,000	\$102,000	\$101,000
Exports ³	31,496	16,974	20,316	23,300	30,568
Imports for consumption ³	208,620	201,328	119,296	145,534	124,094
Consumption, apparent ⁴	774,124	847,354	825,980	748,234	677,526

¹Includes natural and synthetic calcium chloride.

²A large percentage of the total is estimated owing to nonreporting producers.

³Bureau of the Census.

⁴Calculated by using production plus imports minus exports.

TABLE 2
CALCIUM METAL—TYPICAL SPECIFICATIONS

(Parts per million)

Impurity	Commercial	Melted	Redistilled
Magnesium	5,000	5,000	4,000
Nitrogen	500	9,000	70
Aluminum	5,000	5,000	30
Iron	200	300	20
Manganese	400	300	150
Copper	<10	—	<10
Carbon	—	—	150
Minimum calcium content, percent	98.8	98.8	99.5

Source: Quigley Co. Inc., a subsidiary of Pfizer Inc.

TABLE 3
CALCIUM CHLORIDE PRICES

Product and specifications	Value per short ton	Value per metric ton
Calcium chloride concentrate, regular grade, 77% to 80%, flake, bulk, carload, works	\$165	\$182.
100-pound bags, carload, same basis	225	248.
Anhydrous, 94% to 97%, flake or pellet, bulk, carload, works	325	358.
80-pound bags, carload, same basis	330	364.
Process grade, 80-pound bags	300	331.
Calcium chloride, liquid, 30% to 42% basis, tank car, tank truck, barge	113	125.
Liquid, 45% basis	134	148.
Calcium chloride, United States Pharmacopeia, granular, 275-pounds drums, truck load, freight equalized	0.79 per pound	1.74 per kilogram.

Source: Chemical Marketing Reporter. V. 240, No. 27, 1991, p. 35.

TABLE 4
U.S. EXPORTS OF CALCIUM CHLORIDE, BY COUNTRY

Country	1990		1991	
	Metric tons	Value ¹	Metric tons	Value ¹
Canada	16,463	\$3,214,953	25,006	\$4,467,701
Egypt	1,014	259,847	336	325,203
Mexico	250	81,370	338	217,005
Taiwan	1	3,684	1,053	263,234
Trinidad	7	9,148	546	187,094
United Arab Emirates	2,428	659,282	238	104,404
United Kingdom	561	189,082	716	211,830
Other ²	2,576	2,197,298	2,335	2,253,710
Total	23,300	6,614,664	30,568	8,030,181

¹U.S. Customs declared value.

²Other* included different grouping of countries in 1990 Annual Report.

Source: Bureau of the Census.

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF CALCIUM AND CALCIUM CHLORIDE

Year	Calcium		Crude calcium chloride	
	Kilograms	Value ¹	Metric tons	Value ¹
1987	352,089	\$1,918,099	208,620	\$20,916,867
1988	664,419	3,243,663	201,328	21,215,695
1989	679,603	3,210,216	119,296	20,855,518
1990	651,000	3,779,410	145,534	21,341,378
1991	821,457	5,237,589	124,094	18,610,152

¹U.S. Customs, insurance, freight.

Source: Bureau of the Census.

TABLE 6
U.S. IMPORTS FOR CONSUMPTION OF CALCIUM CHLORIDE, BY COUNTRY

Country	1990		1991	
	Metric tons	Value ¹	Metric tons	Value ¹
Crude:				
Canada	109,880	\$13,276,894	92,838	\$11,276,937
Germany, Federal Republic of	9,471	2,264,418	13,639	2,901,992
Mexico	18,251	4,143,726	13,000	3,157,007
Sweden	2,517	291,482	3,950	612,256
Other	5,415	1,364,858	667	661,960
Total²	145,534	2,134,1378	124,094	18,610,152

¹U.S. Customs, insurance, freight.

Source: Bureau of the Census.

TABLE 7
U.S. IMPORTS FOR CONSUMPTION OF OTHER CALCIUM COMPOUNDS

	1990		1991	
	Metric tons	Value ¹	Metric tons	Value ¹
Calcium bromide	16,837	\$6,110,817	15,549	\$7,487,550
Calcium carbide	13,484	6,158,817	14,467	6,920,526
Calcium carbonate, precipitated	20,120	12,819,918	44,839	9,337,750
Calcium cyanamide	414	267,042	700	425,123
Calcium hypochlorite	3,973	6,516,100	6,218	9,479,952
Calcium nitrate	79	10,253,525	63	8,763,094
Dicalcium phosphate	2,380	2,744,325	2,283	2,620,294

¹U.S. Customs declared value.

Source: Bureau of the Census.

CEMENT

By Cheryl Solomon

Ms. Solomon, a physical scientist with 6 years of U.S. Bureau of Mines experience, has been the commodity specialist for cement since 1992. Domestic survey data were prepared by Gail Mason, statistical assistant; and international survey data were prepared by Ron Hatch, international data coordinator.

Cement is the most widely used construction material in the United States. The industry's main product, portland cement, makes up 96% of the total domestic production. The remainder comes from masonry, hydraulic, and aluminous cements.

In 1991, U.S. demand for cement declined, as the basic trend set over the past 4 years continued. Domestic production of portland cement declined by 6%. Cement imported for consumption declined for the fourth year to 8.7 million short tons. Portland cement prices declined marginally due to decline in demand.

The Department of Commerce determined that gray portland cement and clinker from Japan were being sold in the United States at less than fair value. The U.S. International Trade Commission determined that the U.S. cement industry was being injured by imports from Japan.

DOMESTIC DATA COVERAGE

Domestic production and consumption data for cement are developed by means of the portland and masonry cement voluntary survey. Of the 119 cement manufacturing plants to which an annual survey collection request was made, 95 responded, representing 80% of the cement production and consumption data shown in table 1. Estimates were made for nonrespondents using monthly survey data and data received from previous annual surveys.

BACKGROUND

Definitions, Grades, and Specifications

Section 4 of the Annual Book of the American Society for Testing and Materials (ASTM) publishes standards, test methods, definitions, recommended practices, classifications, and specifications for cement, lime, and gypsum.¹

Following is a brief discussion of various types of hydraulic cements and the materials from which they are made.

Clinker.—Clinker is produced by heating a properly proportioned mixture of finely ground raw materials containing calcium carbonate, silica, alumina, and iron oxide in a kiln to a temperature of about 2,700° F at which partial fusion occurs. The fused material, which ranges from fine sand grains to walnut size, is ground with small amounts, 3% to 5%, of calcium sulfate, usually gypsum or anhydrite, to make portland cement.

Portland Cement.—ASTM specification C-150 covers five types of portland cement: Type I, for use when special properties specified for other types are not required; Type II, for general use, especially when moderate sulfate resistance or moderate heat of hydration is desired; Type III, for use when high early strength is required; Type IV, for use when a low heat of hydration is desired; and Type V, for use when high sulfate resistance is required. ASTM specifications also include Type IA, Type IIA, and Type IIIA for the

same uses but with the addition of air entraining compounds to protect concrete against freeze-thaw damage.

White Cement.—White cement is made from iron-free materials of exceptional purity, usually limestone, china clay or kaolin, and silica. The clinker is burned with a reducing flame in the kiln and rapidly quenched in a water spray to keep any iron in the ferrous state to avoid coloration by ferric ions. The clinker is then ground with high-purity white gypsum using ceramic balls and liners in grinding mills. White cement is used in decorative concrete, including terrazzo, highway lane markers, and architectural concrete.

Masonry Cement.—Masonry cement is a hydraulic cement used in mortars for masonry construction. It contains one or more of the following materials: portland cement, portland-pozzolan cement, slag cement, or hydraulic lime, usually with hydrated lime, limestone, chalk, calcareous shale, talc, slag, or clay interground for plasticity. ASTM designation C-91 contains specifications for masonry cement.

Blended Hydraulic Cement.—ASTM designation C-595 covers four kinds of blended hydraulic cements, each with an optional provision for air entraining.

Portland-Blast Furnace Slag.—This is essentially an intimately interground mixture of portland cement clinker and granulated blast furnace slag, or an intimate and uniform blend of portland

cement and fine granulated blast furnace slag in which the slag constituent ranges between 25% to 70% of the total weight of the cement.

Pozzolan.—Pozzolan is a siliceous and aluminous material that in itself possesses little or no cementitious value but will, in a finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. Fly ash is a pozzolanic material obtained from flue gases produced by coal combustion. Natural pozzolans are naturally occurring materials such as diatomaceous earths, opaline cherts and shales, tuffs, volcanic ash, and pumicites. ASTM C-618 covers fly ash and natural pozzolans.

Portland-Pozzolan Cement.—Portland-pozzolan cement is produced by intergrinding portland cement clinker and pozzolan, by blending portland cement or portland-blast furnace slag cement and finely divided pozzolan, or a combination of intergrinding and blending in which the amount of the pozzolan is between 15% and 40% of the total weight of the cement.

Pozzolan-Modified Portland Cement.—The constituents in this type of cement are the same as those for portland-pozzolan cement, and the methods of production are also the same. However, pozzolan makes up less than 15% of the total weight of the blended cement.

Slag Cement.—Slag cement is a finely divided material made from a uniform blend of granulated blast furnace slag and hydrated lime. The slag constitutes at least 70% of the total weight of the blended cement.

Oil-Well Cement.—Oil-well cement was developed to seal oil and gas wells under pressures of 18 to 20,000 pounds per square inch and temperatures up to 400° F in oil and gas wells and 500° F in

steam wells. This cement must remain fluid up to about 4 hours to be effective. The cement is modified by service companies to fit individual well conditions using additives. The average well depth is 4,600 feet, but can range from grass roots depth to 30,000 feet.

The American Petroleum Institute (API) specifications cover requirements for manufacturing eight classes of well cements—A, B, C, D, E, F, G, and H—and Grades O-Ordinary, MSR-Moderate Sulfate-Resistant Grade, and HSR-High Sulfate Resistant Grade.² Changes in the API Specification were set down in 1991, including the elimination of specific well depths in classes A-H cement and the abolition of mandatory testing for classes A, B, and C cement among other changes. The physical and chemical requirements set down previously remained the same.

Expansive Cement.—Expansive cement is a hydraulic cement that tends to increase in volume after setting during the early hardening period. There are three types of expansive cements, types K, M, and S. Expansive cements are used primarily in shrinkage-compensating concrete. ASTM specification C-845 covers all expansive cements.

Aluminous Cement.—Sometimes known as calcium aluminate cement, high-alumina cement, or "Ciment Fondu," aluminous cement is a hydraulic nonportland cement. Special applications of aluminous cement are based on its rapid-hardening qualities, resistance to sulfate action, and refractory properties when used as "castable refractories" and mortars for furnaces and kilns.

Concrete.—Concrete is a proportioned mixture of coarse mineral aggregates of sand and gravel or crushed stone, bound together by a paste of hydraulic cement and water. Volume 04.02 of ASTM standards covers concrete and aggregates.

Admixtures.—Admixtures allow the concrete to be altered to the particular job. Factors such as the durability,

appearance, versatility, and cost effectiveness of the concrete can be manipulated. Most additives modify the hydration of portland cement in some way, by changing the speed of reaction or by dispersing the cement particles more thoroughly throughout the mix. Admixtures reduce the water-cement ratio required in the concrete mix. The following are admixtures in cement:³

Plasticizers.—Plasticizers are water-reducing agents that effectively reduce the quantity of cement required to achieve certain strength or workability characteristics.

Superplasticizers.—Superplasticizers produce highly workable flowing concrete that can, for example, be used for pumping applications. Superplasticizers can also produce high-strength concrete that has a reduced water content and a high compressive strength.

Air-Entraining Agents.—Air-entraining agents cause microscopic air bubbles to be distributed uniformly throughout the concrete. These then act as reservoirs for the water when it freezes, allowing it to expand without harming the structure of the concrete. They can also act as crack inhibitors by preventing small cracks enlarging beyond the extent of the nearest air void. Concrete may be air-entrained to give protection from freeze-thaw cycles. Air-entraining mixtures may entail loss of compressive and tensile strength and thus may be used with plasticizers to restore the strength properties. Fly ash and slag have an air-entraining effect.

Accelerators.—Accelerating admixtures increase the hardening rate of concrete, giving high early strength development. Calcium chloride is the most common accelerator and has been in use since 1885. Accelerators are mainly used in cold weather to normalize the setting time for concrete in a similar way that retarding plasticizers may be used in hot weather to slow down the process.

Waterproofing Aids.—Waterproofing aids are chemical admixtures that provide protection against the wind and rain, and reduce the intake of ground water. Waterproofing aids form a water repellent surface on the concrete and thin hydrophobic layers and voids within the concrete structure.

Polypropylene Fibers.—Polypropylene fibers can inhibit cracks. The fibers take up the stress from drying concrete, thus reducing the tendency for it to crack. They add little to the overall strength of the hardened concrete; however, they impart elasticity during the initial plastic stage of the concrete, which is important for the inhibition of cracks.

Products For Trade and Industry

Portland cement makes up 96% of total domestic output; the remainder is mostly masonry cement with white, expansive, portland slag and pozzolan, waterproof, and a variety of miscellaneous cements accounted for a small percentage of the remainder.

Industry Structure

The industry is composed of 119 cement-producing plants in 39 States. Multiplant operations were being run by 23 companies. Because of overall poor financial performance by the industry during the 1980's and 1990's, many companies have left the cement business or closed plants and began importing finished cement or clinker for grinding into finished cement. Seventeen independent importers have constructed terminals to receive foreign cement for markets near coastal areas.

In the mid- to late 1980's, changes in U.S. cement company ownership to overseas companies were very active. Due to the downturn in the U.S. cement industry and the possibilities to acquire cement companies in Europe, there has been much less interest in foreign acquisition of U.S. cement companies. However, at the end of the year there was still 65% foreign ownership.⁴ In 1991, Blue Circle Industries of London,

England, acquired the Beazer Harleyville, SC, plant and Lafarge Coppee of France finalized its acquisitions of Davenport Cement Co. and Missouri Portland Cement Co. A 50% interest of Riverside Cement of Diamond Bar, CA, was acquired by SsangYong Cement Industrial Co. of Seoul, Republic of Korea. Other overseas companies that have acquired U.S. cement companies in prior years⁵ are S.A. Cimenteries CBR of Belgium, Cementos Mexicanos of Monterrey, Mexico, Holderbank Management and Consulting of Zurich, Switzerland, Onoda Cement of Tokyo, Japan, Ciments Francais of Paris, France, RMC of England, Tarmac PLC of Wolverhampton, England, Titan Cement Co. of Athens, Greece, and a consortium of Spanish cement producers consisting of Asland Cement, Cementos Molins, and Uniland Cement.

The cement industry is forward integrated into the ready-mixed concrete, concrete products, and aggregate industries. Cement industries have also acquired interests in waste management companies.

Resources

Primary raw materials required for cement clinker production are, in order of importance, limestone, clay and shale, and iron ore. In instances where essential chemical components are not present in primary raw materials in the required amount, other mined materials or industrial products may be used as additives to correct these deficiencies. Gypsum is added during the clinker grinding process to make finished portland cement.

Although raw materials for cement manufacturing have not been quantified, they are abundant in most countries. Some countries deficient in raw materials meet their requirements by importing. Many domestic companies have reported reserves of raw materials exceeding 100 years of supply.

Technology

Principal steps in manufacturing portland cement consist of crushing, grinding, mixing, and burning raw materials and grinding the resultant clinker. About 1.8 tons of raw materials is required to make 1 ton of cement.

Raw Material Grinding.—Both dry and wet grinding are used to obtain a fineness that may range from 75% to 90% passing through a 200-mesh sieve. In wet milling, water is added with the mill feed to produce a slurry containing about 65% solids. The raw material is then dried and ground for burning.

Burning.—Burning is the most important operation in manufacturing cement because fuel consumption is a major expense, plant capacity is measured by kiln output, and strength and other properties of cement depend on the quality of the clinker. Burning takes place in a rotary kiln that is a refractory-lined steel cylindrical shell. It rotates on an axis inclined at 3/8 to 1/2 inch per foot toward the discharge end. U.S. kilns range in size from 116 to 760 feet long and 8 to 24 feet in diameter.

Byproducts and Coproducts

There are no major byproducts and coproducts in manufacturing hydraulic cement in the United States. Flotation, a method of beneficiation used by some companies to remove undesirable constituents from raw materials and usually to increase the calcium carbonate content of the kiln feed, produces waste such as silica sand or mica fines that may be marketed. Waste rock quarried in selective mining of usable raw material has been sold for riprap and fill materials or crushed and sold as aggregate for concrete or for road base. Some kiln dusts with high alkali content have been collected and used as fertilizer or processed to recover potash.

Economic Factors

Prices.—Cement prices are greatly influenced by local or regional markets and by the availability of energy and raw materials required for cement manufacturing. Discounts for cash and large-quantity purchases, absorption of freight charges, and the cost of packing bags and pallets add to the complexity of cement price patterns. Competition among producers and, in some instances, stiff competition from imports are also factors that contribute to depressed prices and ultimately limit investment dollars available for capital improvement or expansion.

Costs.—In 1990, the national average total operating costs per ton of cement was \$32.99. These costs did not include sales and corporate management expenses.⁶

Tariffs.—For countries with most-favored-nation status, duties are imposed only on white cement in the amount of 22 cents per metric ton, including the weight of containers. Other hydraulic cement and clinker are duty free. The statutory import duty for countries without most-favored-nation status is \$1.76 per metric ton and \$1.32 per metric ton for all other types of cement and clinker, respectively.

Operating Factors

Environmental Requirements.—The cement industry is faced with environmental challenges in the form of carbon dioxide, sulfur dioxide, and nitrogen oxide emissions. Carbon dioxide, as one of the principal gases contributing to the greenhouse effect, has been an important emissions challenge facing the cement industry. Burning of fossil fuels and calcination, the process in which carbon dioxide is driven from calcium carbonate and magnesium carbonate, leaving free lime and magnesia, contributes roughly one-half of the carbon dioxide generated by cementmakers. Sulfur dioxide emissions also have required emissions control

although they have declined since their peak in the early 1970's.⁷ Sulfur is introduced into the process of cement manufacture in the raw materials and fuel in three forms, as sulfates, sulfides, and organic sulfur compounds, and may leave as sulfates in the dust or clinker, or as gaseous sulfur dioxide contained in the exhaust gas. The problems with nitrogen oxide emissions are more complicated than for sulfur dioxide emissions due to complex mechanisms of nitrogen oxide formation. The clinker burning process causes nitrogen oxides to form, which are harmful to the environment. Reduction in nitrogen oxide emissions has been achieved by using such primary measures as an optimized kiln burner and secondary measures to decompose nitrogen oxide that has already formed.⁸

Another source of pollution associated with cement production is controlling dust from kilns and clinker coolers. That requires the installation of dust collectors such as bag houses and electrostatic precipitators, both of which add considerably to operating costs without improving production. In addition to meeting air quality standards, the industry must also comply with water quality, land use, health and safety, and noise requirements. It has been estimated that capital costs for meeting these requirements can account for 20% to 25% of the capital expenditures for new plants and major additions.

Employment.—In 1990, the average U.S. cement plant employed approximately 135 persons, including clerical but excluding sales and corporate management. By regions, the East North Central had the highest average with 169 employees and the West South Central the lowest, with 96 employees.⁹

Energy Requirements.—The U.S. cement industry consumed an average of 4.127 million British thermal units per ton (Btu/ton) in 1990. The fuel cost per unit of clinker was \$5.84.¹⁰ Substantial energy savings have been achieved since the Federal Government implemented the voluntary energy conservation program in

1972. The installation of improved raw material grinding and processing technology, the use of preheater-precalciner systems for burning raw materials, the conversion from wet to dry process, and the conversion from oil and gas to coal for kiln firing all contributed to improved energy efficiency. Further improvements in energy consumption will result as the cement industry continues to increase its use of municipal, industrial, and hazardous wastes for firing the kiln.

ANNUAL REVIEW

Legislation and Government Programs

The Intermodal Surface Transportation Efficiency Act of 1991 was to provide a significant increase in authorizations for new transportation spending over the next 6 years. The new bill implied a more than 40% increase in highway and mass transit funding compared to the period from 1987 to 1991.¹¹

The Boiler and Industrial Furnace Rule (BIF), under the Resource Conservation and Recovery Act (RCRA), sets emission limits and operating standards for cement kilns and other facilities that burn wastes. Cement companies that burn wastes are covered by BIF.

The Environmental Protection Agency has a mandate under the Beville Amendment of RCRA to study cement kiln dusts and to present a Report to Congress by mid-1993.

Issues

Issues facing the cement industry included those relating to the environment such as the use of alternate fuels, among those hazardous wastes, tire-derived fuels, and others; the use of cement kiln dust as fertilizer or in other applications; and the recycling of cement and concrete. Other issues were the lack of capital for new cement plants, cement dumped in the United States by foreign companies, and foreign ownership of U.S. cement plants.

With respect to the use of alternate fuels, cement kilns offer the capacity to burn large amounts of hazardous wastes

that would otherwise go to an incinerator. The cement kilns use the fuel as opposed to merely burning it up as would an incinerator. In addition, the alternate fuels can mean significant reduction in the use of fossil fuels. The use of tire-derived fuel is another example of the recycling of a product that would otherwise go to landfills. According to the Portland Cement Association, 38% of the plants used waste fuel in 1991, up from 33% in 1990.¹²

Issues relating to cement dumping are covered in the Foreign Trade section of this report. Issues relating to foreign ownership of cement plants are covered under the Industry Structure section of this report.

Production

One State agency and 49 companies operated 119 plants in 39 States. In addition, two companies operated two plants in Puerto Rico, manufacturing hydraulic cement. The production data obtained are arranged by State or groups of States that form cement districts. A cement district may represent a group of States or a portion of a State. The States of California, Illinois, New York, Pennsylvania, and Texas are divided to provide more definitive marketing information within those States as follows:

California, Northern.—Points north and west of the northern borders of San Luis Obispo and Kern Counties and the western borders of Inyo and Mono Counties.

California, Southern.—All other counties in California.

Chicago, Metropolitan.—The seven Illinois counties of Cook, DuPage, Kane, Kendall, Lake, McHenry, and Will.

Illinois.—All other counties in Illinois.

New York, Western.—All counties west of a dividing line following the eastern boundaries of Broome, Chenango,

Lewis, Madison, Oneida, and St. Lawrence Counties.

New York, Eastern.—All counties east of the aforementioned dividing line, except Metropolitan New York.

New York, Metropolitan.—The five counties of New York City (Bronx, Kings, New York, Queens, and Richmond) plus Nassau Counties, Rockland, Suffolk, and Westchester Counties.

Pennsylvania, Eastern.—All counties east of the eastern boundaries of Centre, Clinton, Franklin, Huntingdon, and Potter Counties.

Pennsylvania, Western.—All other counties in Pennsylvania.

Texas, Northern.—All counties north of a dividing line following the northern borders of Burnet, Crockett, Jasper, Jeff Davis, Llano, Madison, Mason, Menard, Milam, Newton, Pecos, Polk, Robertson, San Jacinto, Schleicher, Tyler, Walker, and Williamson Counties.

Texas, Southern.—All counties south of the aforementioned dividing line.

Clinker Capacity.—Clinker capacity in the United States, excluding Puerto Rico, increased slightly to 81.9 million tons. California continued to lead all States in clinker capacity, followed by Texas, Pennsylvania, Michigan, and Missouri. Together these five States accounted for 44% of total U.S. clinker capacity.¹³

By yearend, multiplant operations were being run by 23 companies. The size of individual companies, as a percentage of total U.S. clinker production capacity, ranged from 0.3% to 12%. The 5 largest companies with clinker capacity provided 38% of total clinker capacity; the 10 largest companies with clinker capacity provided a combined 59%. The 10 largest companies, in decreasing order of size of clinker production, were Holnam Inc., Lafarge Corp., Southdown Inc., Lone Star Industries Inc., Blue Circle Inc., Ash Grove Cement Co., Lehigh Portland

Cement, Essroc Materials, Medusa Cement Co., and California Portland Cement Co.

Portland Cement.—Portland cement production decreased by 6% to 69.4 million tons. The decrease was attributed to declines in the construction markets in 1991.

The industry operated 119 plants, including 8 grinding facilities, to produce various types of finished hydraulic cement compared with 120 plants in 1990. California continued to lead all States in the production of cement, followed by Texas, Pennsylvania, Michigan, and Missouri. Together these five States accounted for 45% of total U.S. cement production.

The size of individual companies, as a percentage of total U.S. finished cement production capacity, ranged from 0.4% to 11.8%. The top 10 producing companies, in declining order of production, were Holnam Inc., Lafarge Corp., Lone Star Industries Inc., Southdown Inc., Lehigh Portland Cement Co., Ash Grove Cement, Blue Circle, Essroc, Medusa Cement Co., and California Portland Cement.

Masonry Cement.—At yearend, 80 plants were manufacturing masonry cement in the United States. One plant producing masonry exclusively was Riverton Corp., Riverton, VA.

Aluminous Cement.—Aluminous cement continued to be produced by Lehigh, Buffington, IN; Lone Star Lafarge, Chesapeake, VA; and Aluminum Co. of America, Bauxite, AR.

Fuel Consumption.—According to the Portland Cement Association, a survey of its members indicated that coal and coke accounted for 70.8% of the fuel used.¹⁴ The consumption of electrical energy represented 10% of the fuel used. Fuel used in wet-process plants was 6.3 million Btu/ton, or 29% higher than the dry process of 4.5 million Btu/ton. Kilns without preheaters averaged 5.4 million Btu/ton, those with preheaters averaged

4.4 million Btu/ton, and those with precalciners averaged 3.9 million Btu/ton.

Corporate Changes.—C.H. Beazer PLC was acquired by Hanson Trust PLC.¹⁵ Both companies are based in the United Kingdom. Beazer had owned Gifford-Hill, which therefore ceased to exist as a cement company. Hanson gained a 50% interest in North Texas Cement and Riverside Cement Co. North Texas Cement was a joint venture with Pioneer. Gifford-Hill's Harleyville, SC, plant was purchased by Blue Circle Industries PLC.¹⁶ Lafarge Corp. took over the U.S. assets of Cementia Holdings SA, which will bring an additional 2.5 million tons of capacity to Lafarge, plus 16 cement terminals and more than 30 ready-mix and aggregate operations.¹⁷ SsangYong, the largest player in the Republic of South Korea, which operated the largest clinker production facility in the world, purchased a 50% interest in a joint venture with Beazer of the United Kingdom construction building group to own and operate the plants and terminals of the Riverside Cement Co. in California.

The four plants owned by RC Cement have been grouped under the parent name. Tarmac merged its two plants in Florida and Virginia under the corporate name Roanoke Cement. South Dakota Cement changed its name to Dacotah Cement.¹⁸

Consumption and Uses

Consumer demand for cement in the United States, excluding Puerto Rico, decreased by 11% to 79.4 million tons. This was the fourth year of decline after the 20-year low experienced at the depth of the recession in 1982. According to U.S. Department of Commerce data, housing starts declined 15% to 1.0 million units. The value of new construction put in place declined 9% to \$401 billion. The value of residential construction put in place declined 14% to \$158 billion, primarily in single-unit structures. The value of nonresidential construction put in place declined 17% to

\$97.8 billion, owing primarily to decreases in office and other commercial building construction. Public construction experienced an increase of 9% or \$50.4 billion, caused primarily by spending for public buildings, conservation and development, sewer systems, and water supply facilities.¹⁹

Among the consuming States, California continued to lead all areas in the amount of portland cement consumed followed by, in order of shipments received, Texas, Florida, Illinois, Ohio, and Pennsylvania. Together, these States consumed 40% of total U.S. tonnage.

On a regional basis, all of the nine census regions experienced decreases in consumption. The largest decreases were experienced by the South Atlantic, Pacific, Middle Atlantic, and New England regions, with decreases of 17.5%, 16.3%, 14.0%, and 12.7%, respectively. However, the East North Central, East South Central, and West North Central all experienced declines of between 6.6% and 10.0%. The West South Central and Mountain Regions experienced moderate declines of slightly more than 3%.²⁰

Shipments of domestically produced portland cement from U.S. mills decreased by 8%, while masonry cement shipments decreased by 13%. Cement imported for consumption declined by 34%. This was the fourth consecutive year that imports declined.

Ready-mix concrete producers were the primary consumers of cement, accounting for about 71% of the total, followed by concrete product manufacturers with 13%, highway contractors with 5%, building material dealers with 4%, and other contractors with 3.5%. Smaller amounts were consumed by Federal, State, and other government agencies and by a variety of other miscellaneous users.

Markets and Prices

The average mill value of portland cement declined slightly to \$49.37 per ton while the value of masonry cement increased slightly to \$68.91 per ton.

The average value of cement as reported by Engineering News—Record (ENR) by yearend was \$62.43 per ton. The ENR prices are based on an average per ton value of cement delivered to 20 cities. The prices ranged from a low of \$62.10 in January to a high of \$64.11 in August. The average price change for portland cement for November 1991 increased by 1.6% compared with November 1990.²¹

Foreign Trade

The International Trade Commission (ITC) made a final determination that gray portland cement and clinker from Japan were being sold in the United States at less than fair market value and that the cement industry was materially injured by reason of these imports. This determination followed the investigation that was initiated when a committee of Southern California cement producers filed an antidumping petition with the U.S. ITC and the U.S. Department of Commerce.

In July, the ITC determined that there was reasonable indication that imports of gray portland cement and clinker from Venezuela were being sold in the United States at less than fair value under section 733 of 19 U.S.C. 1673b. In December, the ITC gave notice of the institution of the final antidumping investigation.

A panel of the General Agreement on Tariffs and Trade (GATT) ruled that the United States improperly applied stiff antidumping duties to imports of Mexican cement and recommended that the United States return the more than \$30 million in duties it had collected. In August 1990, the ITC had ruled that imports of Mexican cement were harming U.S. producers, which allowed antidumping duties as high as 57% to be imposed on Mexican cement imports. Mexico and the United States negotiated over the ruling for 1 year. When those negotiations did not lead to a resolution, Mexico asked GATT, the world trade organization based in Geneva, to review the dispute. GATT, however, does not have the power to enforce this recommendation, and it was unlikely that

the United States would return any antidumping tariffs.²²

According to trade data reported by the U.S. Department of Commerce, Bureau of Census, cement imported for consumption in the United States and its possessions and territories was 8.7 million tons or 34% below the level of 1990. This was the fourth year of decline following 3 consecutive years of record-high imports. The decline corresponded to the marginal decrease in total demand resulting from reduced construction activity. Canada, Colombia, Mexico, and Venezuela were the principal import sources accounting for 72% of the total. Clinker accounted for 17% of total imports compared with 32% reached in the peak year of 1985. The average value of foreign cement and clinker, including cost, insurance, and freight, delivered to American ports averaged \$46.27, up 11% from that of 1990.

Florida led all States in the amount of imports received, accounting for 19% of the total. Sixty-four percent or 1.0 million tons of the Florida imports was shipped through the Tampa Customs District. Imports made up about 31% of Florida's portland cement consumption compared with 9% of apparent consumption nationally. Fifty-three percent of imports into Florida came from Venezuela. Los Angeles was the second largest recipient of imported cement, receiving 1.0 million or 12% of the total, about one-half of which was received from Mexico.

Exports of hydraulic cement and clinker as reported by the Bureau of Census increased 26% to 698,000 tons. Canada received 74% of the total.

World Review

World cement production was up slightly at 1.3 billion tons. China continued to lead all nations with 21% of production, followed by the U.S.S.R. with 11%, Japan with 7%, and the United States with 6%. Countries with excess capacity continued to export cement to the United States. Twenty-two countries exported cement to the United

States in 1991, six less than those in 1990. The amount of cement imports declined by 35% because of increased demand within exporting countries and because of a continued decline in demand in certain U.S. markets.

There was considerable activity in plant modernization or expansion by industry throughout the world. The May issue of World Cement magazine gives a world roundup of cement plants.²³

Capacity.—Data in table 9 are estimated and were obtained from a number of different sources, including Government representatives, cement associations, producers, and consultants. Capacity is defined as the maximum quantity of cement that can be produced in a period of time on a normally sustainable basis taking into consideration downtime required for maintenance and repair. Capacity includes operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

During 1991, clinker-producing plants in an estimated 132 countries had a combined annual capacity of about 1.4 billion tons. The seven leading countries, China, the U.S.S.R., Japan, the United States, India, Brazil, and the Federal Republic of Germany, Western states, controlled 52% of world capacity.

In the United States, 46% of the clinker production capacity was concentrated in five States: California, Texas, Pennsylvania, Michigan, and Missouri. At yearend, 207 kilns at 111 plants were being operated, excluding Puerto Rico. The average annual kiln capacity increased to 388,000 tons compared with 365,000 in 1990.²⁴

Canada.—Canada produced 9.4 million tons of cement in 1991, with cement consumption at 6.8 million tons. Canada was the largest exporter of cement to the United States, having exported 3.1 million tons of hydraulic cement and clinker. The Canadian cement industry is highly integrated both vertically and horizontally compared to

that in the United States. There were eight Canadian cement companies, the largest being Lafarge Canada, a subsidiary of France's Lafarge Coppee. Foreign owners controlled 77% of Canadian cement capacity. Canada experienced a worsening of its recession in 1991, with construction down sharply.

Czechoslovakia.—Total cement production was more than 8 million tons with a production capacity of 11.2 million tons. The Czechoslovakian cement industry is relatively modern. Three cement plants used the wet process and 14, the dry process. Total heat consumption on average was 1,026 kilocalories/kilogram. Energy consumption was 109 kilowatt hours/ton. Solid and waste fuels were replacing applied fuels. The use of preheaters was intensified, and environmental protection was improved.²⁵

Greece.—Heracles General Cement Co., Greece's leading cement producer and one of its largest industrial companies, was privatized by the Greek Government according to the Financial Times. Heracles is 70% owned by Greece's state-owned industrial holding company.

India.—The Indian cement industry continued to aggressively expand its production capacity through new plant construction, modernization, and expansion activities. It is anticipated that demand will continue to increase. Cement production in India reached an alltime high of 48.5 million tons. This was the eighth consecutive year of reported production growth.

Japan.—The Japanese Ministry of International Trade and Industry removed that country's cement industry from Government protection. The removal was based on the Ministry's assessment that the Japanese cement industry no longer required favorable tax treatment and low-interest loans to help the industry. In a separate action, Japan's Fair Trade Commission fined 12 leading cement producers a total of \$90 million

after the discovery of illegal cartel arrangements in the Chugoku and Hokkaido regions.²⁶

The U.S. Department of Commerce determined in March 1991 that imports from Japan of gray portland cement and clinker were sold in the United States at less than fair value. The ITC ruled in April 1991 that U.S. cement producers had been injured by dumped Japanese cement. The duties imposed on the Japanese cement industry were 84.7% for Nihon Cement Co., 47.79% for Onoda Cement Co., and 65.22% for all other Japanese producers and exporters of cement and clinker. The duties were effective May 1991.²⁷

Hungary.—Cement production in Hungary was approximately 2.5 million tons, with capacity of about 5 million tons per year, giving a utilization of production capacity of about 42%. Exports of cement, about 53,000 tons, were minimal; imports were about 130,000 tons. Natural gas was the main fuel, utilized at 54%, followed by heavy oil at 38% and coal at 8%.²⁸

Korea, Republic of.—The Republic of Korea has the fifth largest cement industry in the world. Korea's cement production increased 54% over the past 6 years to 40 million tons in 1991. Although the country operated more than 120,000 tons per day of dry-process clinker, which represented an increase in capacity, imports of three million tons were expected to be needed to meet the continuing domestic shortage. China continued to provide the imported cement in the form of bagged cement delivered to Seoul markets. There are eight cement plants that are on the northeast coast near Kangnung on the Sea of Japan and in the region around Chongju. The cement industry in the Republic of Korea is extremely advanced and modernized due to the relative youth of the industry (established only 30 years prior) and to the incorporation of new ideas and processes. The country's entire production capacity is based on dry-process technology. With the rate of

growth in capacity and with expected flattening of demand, it was expected that the Republic of Korea would be exporting more.²⁹

Mexico.—In 1991, the Mexican cement industry produced 25.1 million tons of grey cement, 5.4% more than that in 1990. The national market consumed 23.3 million tons that represented 93% of the total production; 1.8 million tons of cement was exported. The apparent national consumption of grey cement increased by 9.7% in relation to that of 1990. The consumption of cement has remained closely correlated with the behavior of the gross national product; the changes in the latter have an immediate effect on the consumption.

Cementos Mexicanos announced plans to spend about \$1 billion to expand some of its plants and built two new ones to increase its cement production capacity by 35% or 8.8 million tons. Cement demand in Mexico has increased by 10% per year, reportedly. Plants were expected to be built in Guadalajara, Hidalgo, Mexico, Puebla, and the Yucatan.³⁰

The Mexican cement industry is made up of 30 cement plants controlled by 8 industrial groupings, of which CEMEX, formerly known as Cementos Mexicanos, is the largest, controlling about 63% of the market.

Imports of cement from Mexico dropped to 12%, down from 28%, 28%, and 17% in 1988, 1989, and 1990, respectively. The decrease was presumably due to the determination by the ITC that domestic cement producers were being injured by cement from Mexico and the subsequent duties ranging from 3.7% to 58.4% placed on cement imported from Mexico.

Poland.—The cement industry had large, modern dry-process plants working alongside outdated plants with small capacity. The wet process predominated, accounting for 60% of clinker production, which resulted in high heat consumption for clinker burning or 1,330 kilocalories/kilogram of clinker in the whole Polish

cement industry. Therefore, the industry had limited automation of the production process, high labor costs for plant operation and maintenance, relatively high levels of environmental pollution, and high energy consumption. The consumption of cement was low, approximately 10 million tons, or about 60% of total capacity, with 1.8 million tons of exports. In addition, seven plants were reorganized as single joint stock companies—Gorazdze, Oazrow, Strzelce Opolskie, Kujawy, Rudniki, Malogoszcz, and Warta.³¹

Romania.—Clinker production capacity was about 15 million tons per year and cement production capacity more than 23 million tons per year. The cement industry is relatively modern. Seven of the 10 plants in operation had production capacities greater than 2 million tons per year and 2 had more than 1 million tons per year. One plant produced white cement. Eighty-five percent of the kilns was dry kilns with preheaters. Over the past 2 years, however, the capacity utilization has been between 30% and 40%.³²

Saudi Arabia.—The eight cement companies of the Saudi cement industry produced approximately 12 million tons of clinker and sold about 13 million tons cement and clinker during 1991. Industry installed production capacity was rated at about 14.0 million tons per year. More than 1.54 million tons of clinker was exported, along with 492,000 tons of cement, to seven countries in the region and the Far East. The key industry development during 1991 was the establishment of the Saudi Consolidated Cement Co., a merging of the Saudi Bahraini Cement Co. and the Saudi Cement Co. The new venture was to operate about 3.2 million tons of combined annual production capacity.

Taiwan.—Demand for cement in Taiwan reached 19.6 million tons with local producers capable of only outputting 18.9 million tons, leaving a sizable

shortfall to be met from imports from Japan and Indonesia.³³

U.S.S.R.—As of January 1, 1990, there were 398 kilns in service, including 3 kilns with precalciners and 18 shaft kilns. The wet process predominated, with the dry process accounting for only 18% of the kilns. Gas was the main fuel, utilized at 73%, heavy fuel oil at 17.4%, and coal at 9.6%. But it was expected that more coal and also waste fuels would be used in the future. The cement industry faced a number of challenges. Plants needed to be converted to the dry process. However, in Russian and Ukrainian areas, there were deposits of raw material with high moisture content, on average greater than 16%. Modernization of cement mills, with the introduction of closed circuits with new generation classifiers, needed to be accomplished.³⁴

Current Research

The use of supplementary materials has become of increasing importance in concreting practice. These materials can be incorporated in concrete to facilitate several benefits, including the modification and improvement of certain material properties, the conservation of nonrenewable natural resources, and the utilization of industrial byproducts. Blast furnace slag has been widely used in concretes for many years, both as a cementing medium and aggregate.

In the study conducted at the Department of Construction Engineering at the National Taiwan Institute of Technology, the effect of blast furnace slag and fly ash on cement paste was investigated. Blast furnace slag, with a high content of glassy phase, possessed cementitious ability and could be used as a partial substitute for cement. Fly ash is a pozzolanic material and is suitable for massive concrete structures because its addition as a partial substitute for cement would reduce thermal hydration and bleeding, thereby improving the overall durability of the concrete.³⁵

The use of steel slag has been investigated in recent years for use as

aggregate in instant-chilled slag (I.C.S.) The tensile splitting strength of the slag aggregate itself was higher than that of limestone. Compressive, indirect tensile and flexural strengths of I.C.S. slag concretes were greater than those of corresponding control concretes containing limestone aggregate.³⁶

Experimental results at the Department of Silicate Engineering, at the Nanjing Institute of Chemical Technology in China, indicated that alkali slag cements had high strength and durability. The hydration of alkali slag cements is controlled by alkaline activators and is different from that of portland cement. Some activators act as reactants, such as calcium hydroxide and gypsum, but others act simply as catalysts, such as sodium hydroxide.³⁷

The effect of hot weather on the flexural and compressive strength of concrete containing different percentages of granulated blast furnace slag and ground rhyolite tuff for partial replacement of cement was studied at the Hungarian Institute for Building Science in Budapest, Hungary. Hot weather can increase the water demand, the rate of slump loss, the velocity of setting and hardening, and plastic shrinkage. The results indicated that concretes containing blast furnace slag as a partial replacement of cement (up to 40%) cast and cured at 42° C had about the same compressive and flexural strengths at later age as those made with portland cement alone.³⁸

Engineers at the Research Institute of Civil Engineering in Czechoslovakia studied the impact of fly ash fineness on concrete strength. Economy of cement could be reached only with sufficiently fine fly ash.³⁹

The influence of fly ash on the basic characteristics of lightweight and ordinary concretes subject to heat treatment was studied at the Research Institute for Building Structures, Kiev, U.S.S.R. The studies were made of fly ash-containing concretes intended for precast products subject to heat treatment, including lightweight concretes with porous aggregates. The use of fly ash increased the strength of lightweight concretes, reduced cement consumption by 15% to

20%, and permitted a decrease in concrete mean density and heat conduction. The study provided fly ash specifications and characteristics in the U.S.S.R.⁴⁰

The corrosion of steel in concrete with and without silica fume was studied at the Division of Building, Construction and Engineering in Australia. A corrosion cell based on constant impressed voltage of 400 megavolts was developed to study corrosion rate of steel in concrete of different strength levels and in concrete with different silica fume contents. The results indicated that corrosion rate of steel embedded in saturated concrete could be reduced by increasing concrete strength, particularly in a chloride-contaminated environment. The use of 10% silica fume as cement replacement material in making 70 megapascals concrete could have beneficial effects in terms of reduced corrosion rates.⁴¹

An experimental investigation, which was part of a larger research program, studied the relationship between gypsum content porosity and strength in cement. It was hypothesized that total porosity is the main microstructural parameter governing the influence of SO₃ content on the compressive strength of portland cement mortars.⁴²

The rheology and thickening time of high sulfate-resistant class G oil well cement slurries consisting of cement, water, and glycerin were evaluated experimentally at Rogaland Research in Stavanger, Norway. Glycerin contents of 26% by volume or less were found to accelerate the hydration process. At the same time, glycerin was found to act as a viscosifier to the slurry.⁴³ A study that was still in the trial stage was a method to contain and control ocean-based oil spills using portland cement. Usually, oil spills in the ocean are contained through the use of booms and skimmers that recover the spilled oil. Chemical dispersants are another well-known method. However, both of these oil abatement techniques are limited in their application. The new containment technology uses a portland cement-based reagent that is sprayed on an oil spill to form interlocking crystals of calcium

silicate hydrate. Because the calcium silicate hydrate is heavier than the water, it sinks to the bottom, dragging with it the oil particles entrapped in the crystal lattices.⁴⁴

In recent years, the demands for high-quality cement concretes and mortars have greatly increased. This has been due to the problem with the durability of concrete structures. One of the weakest spots in concrete is the interface between cement paste and inserts, such as aggregates. It has been known that the addition of polymers to concretes and mortars in the form of polymer dispersions improved adhesion to substrates and decreased permeability. The aim of the study at the Delft University of Technology in the Netherlands was to investigate the influence of polymer modification on the adhesion of cement paste to aggregates. Three kinds of polymers and two kinds of aggregates were used in the study. In addition, the influence of silica fume on adhesion of cement paste to these aggregates was explored. The strength results were found to be strongly affected by the polymer nature, their contents, aggregate type, and the curing conditions of the composites.⁴⁵

OUTLOOK

The North American Free Trade Act is expected to change the way cement is traded in North America. Increased trade between America, Europe, and Asia, has caused a new distribution of wealth.

Increased emphasis on rebuilding the Nation's infrastructure and transportation has come from the Intermodal Surface Transportation Efficiency Act of 1991. The act provides for authorization of \$155 billion in spending in the 5-year period from 1992 to 1997. The new bill implied more than a 40% increase in highway and mass transit funding compared to the amount spent in 1987-91. The act is likely to increase the demand for cement. How large that increase will be depends on the amount of funds that is actually allocated to highway spending.⁴⁶

It is expected that there will be continued consolidation of plants and companies as well as integration of cement companies into downstream industries, such as in other construction materials industries. There are approximately 2 million tons of new clinker capacity and 860,000 tons of new finish grinding capacity expected to be completed in 1992 and 1993.

The Portland Cement Association forecasts portland cement consumption to be 84.7, 90.6, and 94.2 million tons by 1993, 1994, and 1995, respectively.

Additives to cement, such as slag and fly ash, will continue to play an important role in the cement industry by providing substitutes to the use of cement and imparting special properties to the cement such as sulfate resistance, high strength, etc. Use of alternate fuels such as waste fuel, tires, etc. will also continue to play an important role in the cement industry. Studies conducted by various agencies such as the Environmental Protection Agency and other associations will indicate which regulations the cement industry will need to be concerned about when using alternate fuels.

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¹¹Work cited in footnote 6.

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TABLE 1
PORTLAND CEMENT PRODUCTION, CAPACITY, AND STOCKS IN THE UNITED STATES, BY DISTRICT¹

District	1990					1991				
	Plants active during year	Production ³ (thousand short tons)	Capacity ²		Stocks ⁴ at mills, Dec. 31 (thousand short tons)	Plants active during year	Production ³ (thousand short tons)	Capacity ²		Stocks ⁴ at mills, Dec. 31 (thousand short tons)
			Finish grinding (thousand short tons)	Percent utilized				Finish grinding (thousand short tons)	Percent utilized	
New York and Maine	5	3,174	4,315	73.5	298	5	2,858	4,315	66.2	289
Pennsylvania, eastern	8	4,325	5,771	74.9	357	8	3,818	5,771	66.1	359
Pennsylvania, western	4	1,364	2,195	62.1	160	4	1,559	2,395	65.0	147
Maryland	3	1,807	2,030	89.1	228	3	1,775	1,980	88.6	195
Ohio	4	1,409	2,200	64.0	106	4	1,546	2,125	72.7	119
Michigan	5	5,679	6,090	93.2	306	5	5,045	6,202	81.3	382
Indiana	4	2,462	3,090	79.6	196	4	2,296	3,090	74.2	312
Illinois	4	2,662	2,750	96.8	301	4	2,665	2,850	93.2	310
Georgia and Tennessee	4	2,141	2,595	82.5	247	4	1,947	2,595	75.0	250
South Carolina	3	2,266	3,330	68.0	135	3	2,180	3,340	65.2	124
Kentucky, Virginia, West Virginia	3	2,436	3,122	78.0	224	3	2,019	3,352	60.2	213
Florida	5	2,912	4,675	62.3	299	6	2,806	5,125	54.7	231
Alabama	5	3,629	5,276	68.7	192	5	3,448	5,344	65.5	171
Arkansas and Mississippi	3	1,300	2,225	58.4	83	3	1,252	2,225	56.2	82
South Dakota	1	W	W	W	W	1	W	W	W	W
Iowa	4	2,585	2,725	94.9	264	4	2,403	3,100	77.5	273
Missouri	5	4,663	4,863	95.8	377	5	4,238	5,100	83.1	355
Kansas	5	1,709	2,224	76.8	203	4	1,528	1,950	78.3	181
Oklahoma	3	1,406	1,873	75.0	218	3	1,352	1,873	72.2	221
Texas, northern	7	3,296	5,167	63.7	260	6	3,203	4,968	64.4	214
Texas, southern	6	4,343	6,063	71.6	192	6	4,088	4,863	84.0	184
Idaho, Montana, Utah	5	1,760	2,095	84.0	155	5	1,812	2,095	86.5	148
Colorado, Nebraska, Wyoming	5	2,152	3,920	54.9	187	5	2,201	4,070	54.0	250
Alaska, Oregon, Washington	3	W	W	W	W	3	W	W	W	W
Arizona, Nevada, New Mexico	4	2,048	3,060	66.9	126	4	1,810	3,182	56.8	116
California, northern	3	2,931	3,175	92.3	101	3	2,741	3,175	86.3	94
California, southern	8	7,129	8,001	89.1	288	8	6,607	7,994	82.6	326
Hawaii	1	527	600	87.8	39	1	555	600	92.4	27
Total or average	120	73,902	96,810	76.3	5,768	119	69,449	97,059	71.6	5,727
Puerto Rico	2	1,495	2,116	70.6	31	2	1,402	2,156	65.0	143

W Withheld to avoid disclosing company proprietary data; included in "Total."

¹Includes Puerto Rico. Includes data for three white cement facilities as follows: California (1), Pennsylvania (1), and Texas (1). Includes data for grinding plants (8 in 1990-91) as follows: Alaska (1), Florida (2), Iowa (1), Michigan (1), Pennsylvania (1), and Texas (2).

²Grinding capacity based on fineness necessary to grind Types I and II cement, making allowance for downtime required for maintenance.

³Includes cement produced from imported clinker (1990—1,759,197 tons, 1991—2,056,394).

⁴Includes imported cement. Source of imports withheld to avoid disclosing company proprietary data.

TABLE 2
PORTLAND CEMENT SHIPPED BY PRODUCERS IN THE UNITED STATES, BY DISTRICT¹

District	1990			1991		
	Quantity (thousand short tons)	Value (thousands)	Average per ton	Quantity (thousand short tons)	Value (thousands)	Average ² per ton
New York and Maine	3,321	\$168,247	\$50.67	2,650	\$147,183	\$55.54
Pennsylvania, eastern	4,270	222,026	51.99	3,674	181,597	49.43
Pennsylvania, western	1,351	64,159	47.50	1,550	75,894	48.96
Maryland	1,798	91,172	50.70	1,787	89,194	49.90
Ohio	1,426	72,883	51.11	1,377	65,302	47.42
Michigan	5,906	263,607	44.64	5,186	167,028	32.21
Indiana	2,417	114,414	47.34	2,092	97,558	46.63
Illinois	2,842	116,781	41.10	2,816	116,046	41.21
Georgia and Tennessee	2,211	104,884	47.44	2,109	98,651	46.76
South Carolina	2,464	109,644	44.50	2,365	104,056	44.00
Kentucky, Virginia, West Virginia	2,478	125,068	50.46	2,007	102,455	51.05
Florida	3,954	186,401	47.14	3,169	166,874	52.65
Alabama	3,585	165,344	46.13	3,580	163,668	45.72
Arkansas and Mississippi	1,319	53,806	40.80	1,323	55,140	41.68
South Dakota	W	W	W	W	W	W
Iowa	2,525	122,466	48.50	2,397	100,674	42.00
Missouri	4,481	180,090	40.19	4,095	178,705	43.62
Kansas	1,707	76,564	44.85	1,483	68,953	46.50
Oklahoma	1,544	60,457	39.17	1,277	48,752	38.18
Texas, northern	3,317	147,987	44.62	3,060	147,655	48.25
Texas, southern	4,361	148,692	34.09	4,198	150,488	35.85
Idaho, Montana, Utah	1,644	95,589	58.13	1,596	94,599	59.27
Colorado, Nebraska, Wyoming	2,109	98,316	46.63	2,187	108,299	49.51
Alaska, Oregon, Washington	W	W	W	W	W	W
Arizona, Nevada, New Mexico	2,264	134,556	59.44	1,907	109,189	57.26
California, northern	2,883	176,337	61.16	2,574	153,157	59.50
California, southern	7,149	427,743	59.84	6,632	392,136	59.13
Hawaii	532	46,311	87.01	556	53,300	95.88
Total ³ or average	75,596	3,683,400	48.72	69,594	3,339,763	47.98
Foreign imports ⁴	7,288	368,335	50.54	3,043	152,851	50.23
Puerto Rico	1,486	122,027	82.09	1,395	114,100	81.77
Grand total ⁵ or average	84,370	4,173,762	49.47	74,032	3,606,714	48.72

W Withheld to avoid disclosing company proprietary data; included in "Total."

¹Includes Puerto Rico. Includes data for three white cement facilities as follows: California (1), Pennsylvania (1), and Texas (1). Includes data for grinding plants (8 in 1990-91) as follows: Alaska (1), Florida (2), Iowa (1), Michigan (1), Pennsylvania (1), and Texas (2).

²Based on unrounded data.

³Includes cement produced from imported clinker.

⁴Cement imported and distributed by domestic producers only.

⁵Does not include cement consumed at plant.

TABLE 3
MASONRY CEMENT SHIPPED BY PRODUCERS IN THE UNITED STATES,¹ BY DISTRICT

District	1990			1991		
	Quantity (thousand short tons)	Value (thousands)	Average per ton	Quantity (thousand short tons)	Value (thousands)	Average ² per ton
New York and Maine	122	\$7,057	\$58.05	103	\$5,831	\$56.61
Pennsylvania, eastern	226	16,412	72.46	197	13,629	69.23
Pennsylvania, western	76	6,182	81.21	88	7,243	81.90
Maryland	W	W	W	W	W	W
Ohio	124	10,880	87.50	123	10,760	87.47
Michigan	272	23,880	87.82	224	19,786	88.41
Indiana	368	27,813	75.58	310	22,263	71.86
Illinois	W	W	W	W	W	W
Georgia and Tennessee	175	11,286	64.36	161	10,445	64.87
South Carolina	W	W	W	W	W	W
Kentucky, Virginia, West Virginia	296	19,963	67.53	189	13,203	69.83
Florida	442	27,777	62.89	333	21,218	63.77
Alabama	262	15,462	59.08	245	14,577	59.58
Arkansas and Mississippi	W	W	W	W	W	W
South Dakota	W	W	W	W	W	W
Iowa	W	W	W	W	W	W
Missouri	118	5,683	48.17	94	4,550	48.07
Kansas	39	2,011	50.92	30	1,581	52.70
Oklahoma	W	W	W	W	W	W
Texas, northern	77	5,768	74.54	53	4,566	86.04
Texas, southern	64	4,339	67.58	71	4,250	59.54
Idaho, Montana, Utah	5	267	54.38	5	271	51.56
Colorado, Nebraska, Wyoming	24	1,330	54.94	24	1,278	53.81
Alaska, Oregon, Washington	5	518	103.60	4	401	99.32
Arizona, Nevada, New Mexico	54	4,201	77.22	51	2,826	55.94
California, southern	W	W	W	W	W	W
Hawaii	12	1,870	160.00	9	1,770	190.67
Total or average	3,274	225,404	68.84	2,849	196,313	68.91
Foreign imports ³	41	2,966	71.76	28	2,224	78.12
Grand total ⁴ or average	3,316	228,370	68.88	2,877	198,236	68.90

W Withheld to avoid disclosing company proprietary data; included in "Total."

¹Does not include quantities produced on the job by masons.

²Based on unrounded data.

³Cement imported and distributed by domestic producers only. Source of imports withheld to avoid disclosing company proprietary data.

⁴Data may not add to totals shown because of independent rounding.

TABLE 4
U.S. EXPORTS OF HYDRAULIC CEMENT AND CEMENT CLINKER, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1989		1990		1991	
	Quantity	Value	Quantity	Value	Quantity	Value
Bahamas	8	747	12	963	82	3,020
Canada	447	18,609	449	30,569	531	33,720
Ghana	14	1,018	10	712	13	950
Mexico	27	2,120	31	2,509	25	3,286
Netherlands	1	139	3	274	2	417
Other ¹	15	2,928	49	3,279	45	4,381
Total	512	25,561	554	38,306	698	45,774

¹Includes 37 countries in 1989; 58 in 1990; and 47 in 1991.

Source: Bureau of the Census.

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF HYDRAULIC CEMENT AND CLINKER, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1989			1990			1991		
	Quantity	Value		Quantity	Value		Quantity	Value	
		Customs	C.i.f. ¹		Customs	C.i.f. ¹		Customs	C.i.f. ¹
Canada	3,420	132,558	142,733	3,216	132,138	144,317	3,127	117,757	131,992
Colombia	849	23,594	34,122	1,088	30,219	41,021	1,201	39,133	49,900
France	355	18,909	28,646	443	24,860	35,922	471	28,902	35,293
Greece	1,403	41,945	55,948	808	25,242	32,711	697	21,305	29,071
Japan	2,415	62,239	78,622	2,101	59,368	75,859	331	9,664	13,248
Korea, Republic of	211	5,808	7,440	87	2,150	2,949	—	—	—
Mexico	4,411	118,468	146,452	2,307	56,144	85,906	1,044	35,291	42,817
Spain	1,562	47,218	62,010	1,309	44,071	53,826	699	22,654	29,667
Venezuela	755	22,205	30,149	1,503	44,718	58,462	923	47,743	55,310
Other	360	16,579	19,203	411	20,707	22,074	208	10,837	15,279
Total	15,741	489,523	605,325	13,273	439,617	553,047	8,701	333,286	402,577

¹Cost, insurance and freight.

Source: Bureau of the Census.

TABLE 6
U.S. IMPORTS FOR CONSUMPTION OF CLINKER, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1989			1990			1991		
	Quantity	Value		Quantity	Value		Quantity	Value	
		Customs	C.i.f. ¹		Customs	C.i.f. ¹		Customs	C.i.f. ¹
Canada	407	13,063	14,459	524	14,698	15,091	601	15,192	16,011
Colombia	82	2,012	3,037	419	11,084	16,189	562	13,947	20,043
France	185	8,991	10,949	163	10,580	12,126	93	8,195	9,430
Greece	43	1,155	1,569	—	—	—	—	—	—
Japan	235	5,462	7,598	163	4,289	5,969	—	—	—
Mexico	423	10,511	13,647	87	2,455	3,175	—	—	—
Spain	254	5,469	7,251	57	5,112	7,008	—	—	—
Other	116	3,351	4,018	441	8,692	12,764	207	5,538	7,924
Total	1,745	50,014	62,528	1,854	56,910	72,322	²1,462	42,872	53,408

¹Cost, insurance, and freight.

²Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 7
U.S. IMPORTS FOR CONSUMPTION OF HYDRAULIC CEMENT AND CLINKER, BY CUSTOMS DISTRICT AND COUNTRY

(Thousand short tons and thousand dollars)

Customs district and country	1990			1991		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f. ¹		Customs	C.i.f. ¹
Anchorage:						
Canada	10	1,337	1,665	6	604	778
Japan	66	2,255	3,086	61	1,954	2,775
Total²	77	3,592	4,751	67	2,558	3,553
Baltimore:						
Columbia	105	3,004	3,244	—	—	—
Greece	13	385	571	—	—	—
Japan	(³)	26	32	(³)	47	61
Mexico	16	365	396	—	—	—
Netherlands	(³)	59	64	(³)	52	56
Spain	28	834	1,238	—	—	—
United Kingdom	—	—	—	—	6	8
Total²	162	4,673	5,546	(³)	106	126
Boston:						
Canada	52	1,411	1,469	—	—	—
Greece	151	4,388	5,228	70	2,057	2,645
United Kingdom	—	—	—	(³)	1	2
Total²	203	5,799	6,697	70	2,059	2,647
Buffalo:						
Canada	848	41,556	47,042	708	32,465	36,436
United Kingdom	(³)	4	4	—	—	—
Total²	848	41,560	47,047	708	32,465	36,436
Charleston:						
Mexico	27	795	1,174	—	—	—
Netherlands	(³)	26	30	(³)	13	15
Venezuela	63	1,876	2,830	—	—	—
Total²	90	2,697	4,035	(³)	13	15
Chicago:						
Canada	27	683	683	—	—	—
Germany, Federal Republic of	(³)	6	8	—	—	—
Japan	(³)	47	61	(³)	37	48
Total	27	736	752	(³)	37	48
Cleveland: Canada	192	6,289	8,456	224	7,057	8,982
Columbia-Snake: Japan	280	7,549	10,229	246	6,808	9,268
Detroit:						
Canada	610	22,384	23,173	527	18,097	18,908
France	—	—	—	(³)	7	7
Total²	610	22,384	23,173	527	18,104	18,914
Duluth:						
Canada	98	2,740	3,314	94	2,741	3,221
Japan	(³)	2	2	—	—	—
Total	98	2,742	3,316	94	2,741	3,221

See footnotes at end of table.

TABLE 7—Continued
**U.S. IMPORTS FOR CONSUMPTION OF HYDRAULIC CEMENT AND CLINKER, BY CUSTOMS DISTRICT
 AND COUNTRY**

(Thousand short tons and thousand dollars)

Customs district and country	1990			1991		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f. ¹		Customs	C.i.f. ¹
El Paso:						
Canada	305	8,956	16	—	—	—
Mexico	(²)	14	12,246	123	3,833	5,160
Total	305	8,970	12,262	123	3,833	5,160
Great Falls:						
Canada	73	2,882	3,475	121	2,604	2,805
Germany, Federal Republic of	—	—	—	(²)	4	5
United Kingdom	—	—	—	(²)	31	37
Total²	73	2,882	3,475	122	2,639	2,848
Honolulu:						
Colombia	152	3,636	6,642	170	4,346	7,230
Japan	135	3,589	5,037	—	—	—
New Zealand	100	2,946	4,547	93	2,539	4,153
Total	387	10,171	16,226	263	6,885	11,383
Houston-Galveston:						
Denmark	(²)	15	17	—	—	—
Japan	(²)	43	57	(²)	103	134
Mexico	23	451	586	—	—	—
Total	23	509	660	(²)	103	134
Laredo:						
China	1	81	98	1	100	128
Mexico	94	5,436	6,203	39	2,978	3,447
Total²	95	5,516	6,300	40	3,078	3,575
Los Angeles:						
Australia	—	—	—	(²)	20	22
Austria	—	—	—	(²)	2	3
Colombia	74	2,598	3,093	103	3,478	4,320
France	—	—	—	189	6,333	7,877
Greece	35	1,036	1,584	148	4,515	6,946
Japan	1,186	32,476	40,751	(²)	58	69
Mexico	373	10,288	13,544	562	19,392	22,739
Romania	39	1,068	1,558	—	—	—
Spain	101	3,298	4,033	36	792	1,083
Turkey	45	1,349	1,988	—	—	—
United Kingdom	—	—	—	(²)	1	2
Yugoslavia	(²)	14	18	(²)	11	33
Total²	1,853	52,127	66,569	1,039	34,602	43,094
Miami:						
Belgium-Luxembourg	3	243	403	2	198	288
Colombia	3	94	115	79	2,569	3,381
Denmark	15	913	1,167	17	1,037	1,325
France	(²)	33	40	—	—	—
Greece	138	4,002	5,037	—	—	—

See footnotes at end of table.

TABLE 7—Continued
U.S. IMPORTS FOR CONSUMPTION OF HYDRAULIC CEMENT AND CLINKER, BY CUSTOMS DISTRICT AND COUNTRY

(Thousand short tons and thousand dollars)

Customs district and country	1990			1991		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f. ¹		Customs	C.i.f. ¹
Miami—Continued:						
Mexico	251	5,728	9,224	—	—	—
Spain	172	6,515	8,499	115	4,973	6,707
United Kingdom	(²)	6	6	(²)	5	6
Venezuela	421	12,608	16,407	359	11,780	14,883
Total²	1,002	30,142	40,899	572	20,562	26,590
Minneapolis, MN: Germany, Federal Republic of	(²)	18	20	(²)	19	20
New Orleans:						
Belgium-Luxembourg	(²)	67	76	(²)	52	59
France	273	10,671	13,952	156	6,841	8,793
Portugal	(²)	38	40	—	—	—
Spain	113	3,787	4,886	151	4,470	5,694
Total²	386	14,563	18,954	306	11,363	14,545
New York City:						
Australia	(²)	7	11	—	—	—
Canada	—	—	—	149	4,577	5,664
Colombia	11	278	498	—	—	—
Germany, Federal Republic of	(²)	3	4	—	—	—
Greece	327	11,227	14,273	231	6,869	8,776
Guatemala	50	633	813	—	—	—
Spain	440	16,257	17,836	135	4,952	5,948
United Kingdom	(²)	25	25	(²)	30	32
Venezuela	25	535	830	—	—	—
Total²	853	28,965	34,291	515	16,249	20,420
Nogales: Mexico	272	8,075	9,968	207	6,059	7,338
Norfolk:						
France	61	10,286	18,357	63	13,892	16,273
Greece	—	—	—	151	4,810	6,054
Mexico	71	1,776	2,787	—	—	—
Netherlands	(²)	53	60	(²)	69	78
Spain	60	1,815	2,284	—	—	—
United Kingdom	3	1,040	1,186	1	555	629
Venezuela	214	6,503	8,895	—	—	—
Total²	409	21,473	33,569	216	19,326	23,034
Ogdensburg: Canada	242	8,208	8,899	226	7,743	7,988
Pembina: Canada	236	10,443	12,220	181	4,319	5,384
Philadelphia:						
Colombia	7	222	342	—	—	—
Germany, Federal Republic of	(²)	4	4	—	—	—
Greece	86	2,499	3,534	—	—	—
India	—	—	—	(²)	2	2
Spain	19	567	896	—	—	—
Venezuela	—	—	—	(²)	15	18
Total²	112	3,292	4,777	(²)	17	20

See footnotes at end of table.

TABLE 7—Continued
**U.S. IMPORTS FOR CONSUMPTION OF HYDRAULIC CEMENT AND CLINKER, BY CUSTOMS DISTRICT
 AND COUNTRY**

(Thousand short tons and thousand dollars)

Customs district and country	1990			1991		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f. ¹		Customs	C.i.f. ¹
Portland, ME:						
Canada	(²)	12	15	(²)	16	18
Greece	59	1,705	2,484	—	—	—
Total	59	1,717	2,499	(²)	16	18
Providence:						
Colombia	39	1,099	1,361	—	—	—
Spain	8	349	544	—	—	—
Total	47	1,448	1,905	—	—	—
St. Albans: Canada	327	10,463	12,159	179	5,868	6,705
San Diego:						
Colombia	21	755	924	154	6,161	7,615
Mexico	490	13,944	16,840	113	3,030	4,132
Total²	511	14,699	17,764	267	9,192	11,747
San Francisco:						
Canada	(²)	176	1,879	(²)	2	2
Colombia	35	2	3	176	9,127	9,670
France	—	—	—	(²)	2	2
Greece	—	—	—	96	3,054	4,650
Japan	150	4,623	6,003	—	—	—
Korea, Republic of	87	2,150	2,949	—	—	—
Mexico	152	3,959	5,439	—	—	—
Yugoslavia	(²)	4	6	—	—	—
Total²	425	10,914	16,279	273	12,185	14,324
San Juan, PR:						
Belgium-Luxembourg	6	458	783	4	310	530
Canada	1	2	4	—	—	—
Colombia	159	5,028	6,391	331	8,100	10,916
Denmark	13	1,025	1,309	16	1,298	2,130
Honduras	50	1,182	1,552	—	—	—
Mexico	(²)	2	4	—	—	—
Venezuela	2	89	93	25	571	776
Total²	229	7,786	10,137	377	10,279	14,352
Savannah:						
Colombia	12	312	316	—	—	—
Denmark	6	479	590	2	209	246
France	—	—	—	(²)	3	4
United Kingdom	(²)	2	3	—	—	—
Total²	18	793	908	3	213	249
Seattle:						
Canada	501	21,057	21,723	712	31,844	35,104
China	(²)	10	12	—	—	—
Japan	284	7,754	10,596	24	656	893
Spain	57	1,559	2,521	—	—	—
Venezuela	51	1,701	2,331	—	—	—

See footnotes at end of table.

TABLE 7—Continued
U.S. IMPORTS FOR CONSUMPTION OF HYDRAULIC CEMENT AND CLINKER, BY CUSTOMS DISTRICT AND COUNTRY

(Thousand short tons and thousand dollars)

Customs district and country	1990			1991		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f. ¹		Customs	C.i.f. ¹
Seattle—Continued:						
Total ²	892	32,081	37,183	736	32,500	35,998
Tampa:						
Belgium	(³)	13	17	—	—	—
Colombia	449	W	W	153	4,325	5,527
Denmark	65	W	W	65	4,076	5,210
France	108	W	W	63	1,823	2,335
Mexico	234	5,312	7,493	—	—	—
Spain	312	9,090	11,089	262	7,465	10,234
Venezuela	700	20,340	25,730	496	16,034	19,901
Total ²	1,867	53,841	68,166	1,039	33,724	43,208
Virgin Islands of the United States:						
Antigua	2	63	79	—	—	—
Barbados	2	44	49	—	—	—
Colombia	21	947	1,029	35	1,027	1,240
Denmark	—	—	—	(³)	1	1
Italy	2	69	81	2	60	83
Japan	(³)	4	4	—	—	—
Leeward and Windward Islands	3	62	87	—	—	—
Panama	—	—	—	1	41	76
Trinidad and Tobago	8	237	273	3	76	84
Venezuela	27	1,066	1,344	44	19,358	19,750
Total ²	64	2,492	2,945	85	20,563	21,234
Wilmington, NC: Germany, Federal Republic of	(³)	8	8	—	—	—
Grand total ²	13,273	439,617	553,047	8,701	333,286	402,578

W Withheld to avoid disclosing company proprietary data; included in "Total."

¹Cost, insurance, and freight.

²Data may not add to totals shown because of independent rounding.

³Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF CEMENT AND CLINKER

(Thousand short tons and thousand dollars)

Year	Roman, portland, other hydraulic cement		Hydraulic cement clinker		White nonstaining portland cement		Total	
	Quantity	Value (customs)	Quantity	Value (customs)	Quantity	Value (customs)	Quantity	Value (customs)
1987	13,782	384,989	3,668	79,373	276	24,170	17,726	488,532
1988	15,225	438,978	1,919	48,626	344	28,119	17,488	515,723
1989	13,601	410,326	1,745	50,014	395	29,183	15,741	489,523
1990	11,033	354,662	1,854	56,910	386	28,045	13,273	439,617
1991	6,873	247,137	1,462	42,872	365	43,276	¹ 8,701	333,286

¹Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 9
WORLD CEMENT ANNUAL
PRODUCTION CAPACITY,
DECEMBER 31, 1991¹

(Million short tons)

Country	Rated clinker capacity* ¹
North America:	
Canada	16
Mexico	27
United States (including Puerto Rico)	86
Total	129
South America:	
Argentina	13
Brazil	49
Venezuela	9
Other	20
Total	91
Europe:	
Belgium	10
Czechoslovakia	13
France	26
Germany, Federal Republic of:	
Eastern states	14
Western states	46
Greece	19
Italy	45
Poland	20
Portugal	9
Romania	18
Spain	40
Turkey	25
U.S.S.R.	154
United Kingdom	20
Yugoslavia	10
Other	95
Total	564
Africa:	
Algeria	13
Egypt	25
South Africa, Republic of	12
Other	30
Total	80
Asia:	
China	223
India	58
Indonesia	22
Japan	97
Korea, North	11

See footnotes at end of table.

TABLE 9—Continued
WORLD CEMENT ANNUAL
PRODUCTION CAPACITY,
DECEMBER 31, 1991¹

(Million short tons)

Country	Rated clinker capacity* ¹
Asia—Continued:	
Korea, Republic of	36
Thailand	12
Taiwan	22
Other	34
Total	515
Oceania:	
Australia	9
Other	2
Total	11
World total	1,390

*Estimated.

¹Includes capacities of operating plants as well as plants on standby basis.

TABLE 10
HYDRAULIC CEMENT: WORLD PRODUCTION, BY COUNTRY¹

(Thousand short tons)

Country ²	1987	1988	1989	1990	1991*
Afghanistan*	110	110	110	¹ 123	120
Albania*	945	¹ 822	¹ 831	¹ 830	770
Algeria	⁸ 313	⁷ 931	⁷ 517	⁶ 985	7,055
Angola*	390	1,100	1,100	1,100	1,100
Argentina	6,947	6,667	4,927	4,000	4,410
Australia	6,469	7,055	⁷ 165	⁷ 165	7,440
Austria	4,985	5,250	5,235	⁵ 404	5,510
Bangladesh ⁴	342	343	345	³ 60	365
Barbados	226	203	² 37	¹ 275	275
Belgium	6,271	7,111	⁷ 408	⁷ 638	7,600
Benin*	331	220	² 75	³ 00	300
Bolivia	437	499	557	⁶ 18	605
Brazil	28,076	27,919	28,531	²⁸ 550	28,660
Bulgaria	6,056	6,101	⁵ 476	⁵ 159	59,200
Burma	429	385	434	⁴ 14	405
Canada	¹³ 878	¹³ 267	¹³ 043	¹² 787	12,125
Chile	1,757	2,021	¹ 900	¹ 990	1,985
China*	198,000	²³¹ 000	228,000	224,000	273,000
Colombia	6,575	⁷ 456	7,323	⁶ 967	7,055
Congo*	⁴ 2	64	³ 134	³ 100	113
Costa Rica	641	613	882	¹ 095	990
Côte d'Ivoire*	³ 719	770	⁵ 50	550	550
Cuba	3,897	3,931	⁴ 140	² 866	2,865
Cyprus	941	956	1,149	¹ 249	³ 1250
Czechoslovakia	11,430	12,097	12,002	¹¹ 260	⁹ 148
Denmark	2,080	1,853	² 209	¹ 825	2,205
Dominican Republic	¹ 200	1,647	1,764	1,168	1,100
Ecuador	2,364	2,425	2,480	² 500	2,425
Egypt	9,641	10,789	¹⁰ 479	¹⁶ 864	16,535
El Salvador	669	687	697	⁷ 07	705
Ethiopia	386	447	⁴ 08	³ 75	320
Fiji	65	49	64	⁷ 9	100
Finland	1,572	1,658	1,760	¹ 836	1,765
France	25,970	27,888	²⁹ 580	²⁹ 088	28,660
Gabon	155	146	127	¹ 27	125
Germany, Federal Republic of					
Eastern states	13,702	13,790	¹³ 519	¹¹ 000	NA
Western states	27,853	28,897	31,415	³³ 572	NA
Total	41,555	42,687	44,934	44,572	46,300
Ghana	302	526	623	⁷ 44	745
Greece	14,515	14,388	13,817	¹⁵ 371	14,880
Guadeloupe*	210	220	220	220	220
Guatemala	1,459	1,660	1,779	¹ 846	1,875
Haiti	278	276	² 40	316	220
Honduras	497	617	715	⁷ 19	720
Hong Kong	2,454	2,413	2,360	1,993	1,830
Hungary	4,578	4,269	4,252	⁴ 335	2,975

See footnotes at end of table.

TABLE 10—Continued
HYDRAULIC CEMENT: WORLD PRODUCTION, BY COUNTRY¹

(Thousand short tons)

Country ²	1987	1988	1989	1990	1991 ³
Iceland	144	146	130	¹ 122	125
India	40,763	44,900	⁵ 50,706	⁵ 54,013	55,115
Indonesia	13,055	13,495	15,541	15,170	³ 17,806
Iran	14,031	13,450	¹ 13,800	¹ 14,330	16,535
Iraq ⁴	11,000	³ 11,600	13,800	¹ 11,025	5,510
Ireland	1,596	1,857	¹ 1,791	¹ 1,791	1,765
Israel	2,454	2,564	2,523	³ 3,161	3,200
Italy	41,069	41,760	⁴ 43,414	⁴ 43,541	44,090
Jamaica	337	409	⁴ 488	⁵ 571	575
Japan	78,871	85,489	87,873	⁹ 93,085	⁹ 98,326
Jordan	² 2,500	2,015	² 2,127	² 2,006	1,985
Kenya	1,456	1,366	1,341	1,666	1,650
Korea, North ⁵	9,900	13,000	18,000	18,000	18,000
Korea, Republic of	28,287	31,961	33,592	37,038	37,480
Kuwait	1,120	979	1,224	⁸ 880	330
Lebanon ⁶	1,000	1,000	1,000	1,000	1,000
Liberia	116	117	94	⁵ 55	—
Libya ⁷	² 2,976	3,000	3,000	3,000	3,000
Luxembourg	561	621	⁶ 610	⁶ 650	605
Madagascar	⁵ 53	40	² 26	² 26	25
Malawi	80	72	⁸ 85	⁸ 85	85
Malaysia	3,655	4,161	5,284	⁶ 6,483	8,265
Mali ⁸	24	28	22	22	22
Martinique ⁹	220	220	220	220	220
Mauritania	88	99	99	⁹ 99	99
Mexico	24,633	24,816	25,095	² 26,345	29,430
Mongolia ¹⁰	600	550	570	485	440
Morocco ¹¹	4,200	¹ 4,652	⁴ 4,630	⁴ 4,630	4,630
Mozambique ¹²	80	⁷ 76	88	⁸ 88	88
Nepal	167	237	240	118	110
Netherlands	3,229	3,768	3,903	4,111	3,590
New Caledonia ¹³	55	66	⁷ 74	70	70
New Zealand	970	895	804	⁸ 830	830
Nicaragua ¹⁴	110	110	³ 144	¹ 155	155
Niger	⁴ 44	29	30	³ 30	31
Nigeria	4,189	3,748	³ 3,860	³ 3,860	3,860
Norway	1,807	1,574	1,516	¹ 1,390	1,265
Oman	926	953	1,044	¹ 1,102	1,100
Pakistan ¹⁵	7,530	⁷ 7,761	7,700	7,900	7,935
Panama ¹⁶	385	220	³ 186	³ 330	330
Paraguay	288	354	360	³ 360	360
Peru	2,849	² 2,771	² 2,320	² 2,409	2,205
Philippines	3,660	4,700	⁴ 4,400	⁴ 4,400	4,960
Poland	¹ 17,736	¹ 18,722	¹ 18,877	¹ 13,889	13,260
Portugal ¹⁷	³ 6,451	⁶ 6,500	6,600	6,600	6,600
Qatar	³ 330	³ 330	³ 331	² 294	370
Romania ¹⁸	15,760	15,400	15,400	14,300	14,330

See footnotes at end of table.

TABLE 10—Continued
HYDRAULIC CEMENT: WORLD PRODUCTION, BY COUNTRY¹

(Thousand short tons)

Country ²	1987	1988	1989	1990	1991 ³
Rwanda	76	64	75	67	66
Saudi Arabia	9,474	¹ 12,071	¹ 12,613	¹ 13,230	13,230
Senegal	410	431	419	⁵ 518	550
Singapore	1,684	1,759	1,881	2,041	2,425
South Africa, Republic of	7,424	9,354	8,852	⁸ 8,800	8,265
Spain (including Canary Islands)	² 25,371	² 26,865	³ 30,175	³ 30,966	³ 30,397
Sri Lanka ⁴	660	440	440	440	440
Sudan ⁴	¹ 134	¹ 155	165	¹ 184	185
Suriname ⁴	55	55	55	55	55
Sweden	2,484	⁴ 4,357	⁵ 5,570	⁵ 5,512	5,510
Switzerland	5,089	5,473	6,020	⁵ 5,739	5,730
Syria	4,266	3,671	3,859	³ 3,860	3,860
Taiwan	17,226	19,049	19,889	² 20,348	² 21,373
Tanzania ⁴	330	330	330	330	330
Thailand	10,858	12,692	16,561	¹ 19,901	19,900
Togo	407	416	429	⁴ 440	440
Trinidad and Tobago	³ 360	397	419	483	485
Tunisia ⁴	3,750	³ 3,750	³ 3,750	³ 3,750	3,750
Turkey	24,228	24,995	26,235	² 26,905	² 28,691
Uganda	12	10	¹ 11	¹ 11	11
U.S.S.R.	151,462	153,771	154,804	¹ 151,371	140,000
United Arab Emirates	3,424	3,285	3,430	³ 3,289	3,320
United Kingdom	15,775	18,195	¹ 18,573	¹ 15,432	13,230
United States (including Puerto Rico)	79,501	78,252	78,559	78,606	³ 77,000
Uruguay	442	479	⁶ 617	¹ 550	550
Venezuela	6,735	6,833	4,971	5,765	⁶ 6,985
Vietnam	7,539	2,154	² 2,200	² 2,800	330
Yemen	838	712	⁷ 770	⁸ 882	880
Yugoslavia	9,880	9,744	9,436	8,768	8,270
Zaire	542	546	⁵ 500	⁵ 508	495
Zambia	413	446	425	⁴ 415	415
Zimbabwe	894	855	793	⁸ 800	770
Total	¹ 1,161,256	¹ 1,187,620	¹ 1,265,568	¹ 1,270,970	1,287,565

¹Estimated. ²Revised. NA Not available.

³Table includes data available through June 28, 1992.

⁴In addition to the countries listed, Cameroon produces cement, but available information is inadequate to make reliable estimates of output levels.

⁵Reported figure.

⁶Data are for the year ending June 30 of that stated.

CHROMIUM

By John F. Papp

Dr. Papp, a physical scientist with 20 years' U.S. Bureau of Mines experience, has been the commodity specialist for chromium since 1983. Domestic survey data were prepared by Steve Frauenheim and Robin Johnson, mineral data assistants; chromite world production data, by country, were prepared by Audrey D. Wilkes, international data coordinator. Cost of production data was prepared by Edward H. Boyle, Minerals Availability Field Office, Division of Statistics and Information Services. (All tonnages are in metric tons unless otherwise specified.)

Chromium has a wide range of uses in metals, chemicals, and refractories. It is one of the Nation's most important strategic and critical materials. Chromium use in iron, steel, and nonferrous alloys enhances hardenability and resistance to corrosion and oxidation. The use of chromium to produce stainless steel and nonferrous alloys are two of its more important applications. Other applications are in alloy steel, plating of metals, pigments, leather processing, catalysts, surface treatments, and refractories.

Because the United States has no chromite ore reserves and a limited reserve base, domestic supply has been a concern during every national military emergency since World War I. World chromite resources, mining capacity, and ferrochromium production capacity are concentrated in the Eastern Hemisphere. The National Defense Stockpile (NDS) contains chromium in various forms, including chromite ore, chromium ferroalloys, and chromium metal in recognition of the vulnerability of long supply routes during a military emergency.

Research is conducted by the Federal Government to reduce U.S. vulnerability to potential chromium supply interruption. That research covers both domestic resource utilization and alternative materials identification. Domestic chromium resources include mineral deposits and recyclable materials. The U.S. Geological Survey and the U.S.

Bureau of Mines evaluate U.S. territory for chromium mineral deposits. The U.S. Bureau of Mines also studies minerals extraction and processing and materials substitution and recycling. Alternative materials research is also conducted by the National Aeronautics and Space Administration, the National Institute of Standards and Technology, the Department of Defense, and the Department of Energy.

World chromite ore reserves are more than adequate to meet anticipated world demand.

DOMESTIC DATA COVERAGE

Domestic data coverage of the primary consuming industries—chemical, metallurgical, and refractory—are developed by the U.S. Bureau of Mines by means of the voluntary monthly "Chromite Ores and Chromium Products" survey. The companies listed in table 11 by industry accounted for 100% of the chromite consumption data by industry in the current year of table 13. All of the refractory companies and all of the chemical companies that consumed chromite in 1991 reported to the Bureau, while 75% of the metallurgical companies reported. Consumption was estimated for the remaining 25% of the metallurgical firms.

Domestic production data for chromium ferroalloys and metal are developed by the U.S. Bureau of Mines by means of two separate, voluntary

surveys. These two surveys are the monthly "Chromite Ores and Chromium Products" and the annual "Ferroalloys." Production by the metallurgical companies listed in table 11 represented 100% of the domestic production shown in the current year of table 12. Seventy-five percent of those companies responded to both surveys. Production for the remaining 25% was estimated.

BACKGROUND

Chromium owes its prominence as a commodity to its use in stainless steel. Stainless steel was invented in the early 1900's. Soon thereafter electric furnaces evolved that could smelt chromite into ferrochromium. Before about 1960, ferrous alloys required the addition of as little carbon as possible because carbon could not efficiently be removed from molten steel. Thus, the production of low-carbon, high-chromium alloys (typically less than 0.1% carbon and more than 65% chromium) in or near steel producing centers, was the common practice. To make this ferrochromium, high chromium-to-iron ratio ores were required (ratios greater than about 2:1).

Since 1960, major changes have occurred in the chromium industry because of changes in steelmaking technology. The development of ladle refining techniques (i.e., processes that permit the chemical modification of liquid metal) such as argon-oxygen decarburization, permitted the steel

industry to shift from the more costly low-carbon ferrochromium to the less costly high-carbon ferrochromium as its major source of chromium units. This shift in ferrochromium grade has been accompanied by a shift in quantity of production among ferrochromium-producing countries. Since the 1970's, chromite ore-producing countries have developed their own ferrochromium production capacities. As a result, ferrochromium production has moved from the major stainless steel-producing centers, Japan, the United States, and Western Europe, to chromite-producing countries, Finland, the Republic of South Africa, Turkey, and Zimbabwe. With the exception of Japan, only minor ferrochromium production remains in the major stainless steel-producing countries. In particular, the Republic of South Africa, whose ores have a chromium-to-iron ratio of about 1.2:1, has increased its high-carbon ferrochromium production dramatically. Significant, but declining, quantities of ferrochromium continue to be produced in Japan.

Once chromium is incorporated into stainless steel, it is used in many different ways. Stainless steel is used in many industrial applications that benefit from oxidation or corrosion resistance or in applications that benefit from the ease with which stainless steel may be cleaned. Uses that are common to the experience of many people include kitchen and eating utensils, sinks, and automobile exhaust components or systems. Chromium is also used in chemicals for a variety of purposes.

Chromite, the mineral from which chromium is derived for use in the metallurgical and chemical industries, is used directly by the refractory industry to produce heat-, spalling-, corrosion-, and abrasion-resistant bricks for metallurgical and high-temperature industrial mineral processing applications. Chromite is not mined domestically; thus, the United States is 100% import dependent to meet domestic chromite demand. Some domestic chromium demand is met by recycling. Chromium is a critical and strategic material contained in the NDS to

ensure adequate supply in the event of a national defense emergency.

Definitions, Grades, and Specifications

U.S. industry sets chemical and physical specifications for chromium materials through the American Society for Testing and Materials (ASTM). Other organizations also make specifications for chromium materials. The Defense Logistics Agency (DLA), in cooperation with the Department of Commerce, maintains purchase specifications for chromium materials contained in the NDS. The Treasury Department, in cooperation with the Department of Commerce and signatories to the General Agreement on Tariffs and Trade, maintains definitions of chromium materials for the purpose of recording trade and applying tariff duties. (See table 1.)

The import category "chromite ore and concentrates made therefrom" is subdivided by chromic oxide content as follows: containing not more than 40% chromic oxide, containing more than 40% and less than 46% chromic oxide, and containing 46% or more chromic oxide. Producers of chromite ore and concentrate typically specify chromic oxide content; chromium-to-iron ratio; and iron, silica, alumina, magnesia, and phosphorous contents. They also specify the size of the ore or concentrate. Typically, chromic oxide content ranges from 36% to 56%, with values in the 40% to 50% range being most common. Chromium-to-iron ratios typically range from about 1.5:1 to about 4.0:1, with typical values of about 1.5:1 to 3.0:1. In trade, the chromite ore is also called chromium ore, chromite, chrome ore, and chrome.

The import category "chromium ferroalloys" is subdivided into ferrochromium and ferrochromium-silicon. Ferrochromium-silicon, also called ferrosilicon-chromium and chromium silicide, is not further classified. Ferrochromium is classified by its carbon content as containing not more than 3% carbon, more than 3% but not more than 4% carbon, or more than

4% carbon. Producers of ferrochromium typically classify their material as low- or high-carbon or charge-grade ferrochromium. Charge-grade ferrochromium is also called charge chrome. Producers of chromium ferroalloys typically specify chromium, carbon, silicon, phosphorous, and sulfur contents and material size. Ferrochromium-silicon typically contains 24% to 40% chromium, 38% to 50% silicon, and 0.05% to 0.1% carbon. Ferrochromium typically contains 50% to 75% chromium and 0.05% to 8% carbon. Low-carbon ferrochromium typically contains 55% to 75% chromium and 0.02% to 0.1% carbon. High-carbon ferrochromium typically contains 60% to 70% chromium and 6% to 8% carbon. Charge-grade ferrochromium typically contains 50% to 55% chromium and 6% to 8% carbon.

Products for Trade and Industry

Chromium is primarily used in the metallurgical industry as an alloying element. Small quantities of chromium are alloyed with (i.e., added to) a base metal to achieve certain desired properties not attainable with the base metal alone. Before its use as an alloying element, chromium was used predominantly in chemicals to make pigments or to plate metals. Chromite is used as a refractory material. Refractories resist degradation when exposed to heat. As a pigment, chromium provides color to many end products and corrosion protection to ferrous metals. As a plating material, chromium provides a lustrous or a hard finish and corrosion protection to the substrate metal. As a refractory, chromite found major use in blast furnace iron production. The decline in use of this process has resulted in a corresponding decline in chromite refractory use. Environmental concern over hexavalent chromium contamination has resulted in reduced use or increased expense of chromium use in pigments and plating. Chromium is traded primarily as chromite ore or as ferrochromium. Substantial amounts of chromium

chemicals, pigments, and metal are also traded.

Industry Structure

Stainless steel was developed in about 1900. Since then, stainless steel has grown to become the major end use of chromium. Chromium is used in stainless steel production in the form of ferrochromium, a product of smelting chromite ore with a carbonaceous material (chemical reductant) and siliceous materials (flux material). The production of stainless steel evolved in association with the major steel-producing centers. The production of ferrochromium developed in conjunction with the production of stainless steel at those steel-producing locations.

In a trend toward vertical integration, chromite-producing countries have been developing ferrochromium and stainless steel production capacity. This trend has worldwide impact. Formerly, ferrochromium was produced mainly by Europe, Japan, and the United States, the major steel producers. The U.S. trend to obtain chromium in the ferroalloy form is a result of the world trend to produce ferrochromium in chromite-producing countries.

The structure of the chromium industry from a material processing perspective begins with mining of chromite ore. (See figure 1, chromium material flow.) Once mined, the ore is beneficiated. The resulting chromite ore or concentrate made therefrom may be consumed in the refractory, chemical, or metallurgical industry. Chromite ore is consumed in the refractory industry for its chromite mineral content. The chromite is typically crushed, ground, and sized. It is then mixed with magnesite to make chrome-magnesite bricks that are subsequently consumed in the steel, glass, or cement industry. The chromite refractories are used to line steelmaking furnaces, cement kilns, or heat exchangers associated with glass production. (See figure 1.)

Chromite ore consumed in the chemical or metallurgical industry is processed to extract the chromium from

the chromite mineral. Chromite ore consumed in the chemical industry is kiln roasted, and the chromium is leached out in the form of sodium bichromate. The sodium bichromate is further processed to make chromic acid and other chromium chemicals and pigments. Chromic oxide is a chemical industry product. Chromite ore consumed in the metallurgical industry is smelted to produce ferrochromium. In effect, the oxygen is removed from the iron-chromium-oxygen mineral, leaving an iron-chromium alloy, ferrochromium. Ferrochromium is produced to meet a variety of chemical and physical specifications. Several variations of the ferrochromium production process are practiced; the submerged electric arc furnace is central to each process. Ferrochromium is the source of chromium units for alloys, especially ferrous alloys. When nonferrous alloys require chromium and the iron is undesirable, chromium metal is used. Chromium metal is produced from ferrochromium by an electrolytic process or from chromic oxide by an aluminothermic process.

The major vertical structure of the chromium industry is mining-smelting-stainless steelmaking. In some instances, the ownership of mining operations, smelters, and stainless steel production facilities is integrated. In many other cases, integration is limited to mining and smelting or to smelting and stainless steelmaking. Often the ownership of operations is shared. Major mining, smelting, or stainless steel production facilities are typically privately owned by large companies or groups of companies. (See tables 2 and 3.)

Geology-Resources

The geology of many chromium deposits has been characterized.¹ The data in table 23 are rated reserves and reserve base for major chromite ore-producing countries.² The data on chromite reserves and resources are categorized according to a general U.S. Bureau of Mines-U.S. Geological Survey classification system applicable to all minerals. The definition of reserves and

reserve base are published in Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals." The distribution of chromite deposits into reserves, reserve base, and resources categories is determined by the physical and chemical nature of the ore (physical factors) and by mining and market economics (economic factors). Resources are a concentration of naturally occurring material from which a commodity may currently or potentially be extracted. Resources are divided into identified and undiscovered. As used here, resources refers only to identified resources that are further subdivided into demonstrated and inferred resources. The reserve base is the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. The reserve base includes those resources that are currently economic, marginally economic, and some of those that are currently subeconomic.

Reserves are that part of the reserve base that could be economically extracted or produced at the time of determination. Reserves include only recoverable materials. Reserve values are included in reserve base values.

The term "reserves" is commonly used with a variety of definitions. Even when the definition given here is used, the quantitative value of reserves could vary owing to differing physical and economic criteria applied to a deposit by different analysts.

Technology

Mining.—A wide variety of mining technology is applied to the surface and subsurface mining of chromite ore. Most ore comes from large mechanized mines. However, small labor-intensive mining operations contribute to world supply.

Beneficiation.—The amount of beneficiation required and the techniques used depend on the ore source and end-use requirements. When the chromite is clean, only hand sorting of coarse material and gravity separation of fine

material may be required. When the ore is lumpy and mixed with host rock, heavy-media separation may be used. When the chromite mineral occurs in fine grains intermixed with host rock, crushing may be used in conjunction with gravity separation and magnetic separation.

Smelting.—The smelting of chromite ore to produce ferrochromium requires electric arc furnace technology. Early electric furnaces having power ratings in the kilovolt-ampere range have developed into modern furnaces having power ratings of about 50 megavolt-amperes. Closed and partially closed electric arc furnaces replaced open furnaces in the 1970's to improve pollution control, efficient furnace operation, and safety.

Ferrochromium is produced from chromite ore by smelting a mixture of the ore, flux materials (e.g., quartz, dolomite, limestone, and aluminosilicates), and a carbonaceous reductant (wood, coke, or charcoal) in an electric arc furnace. If the ore is lumpy, it can be fed directly into the furnace. However, if the ore is not lumpy, it must be agglomerated before it is fed into the furnace. (See Energy Requirements under Operating Factors.) Efficient operations recover chromium lost to furnace fume by collecting and remelting the dust and recover chromium lost to slag by crushing and beneficiating the slag. The chromium content of the ferrochromium is determined by the chromium-to-iron ratio of the chromite ore.

The shift from high-chromium, low-carbon ferrochromium to low-chromium, high-carbon ferrochromium, commonly called charge-grade ferrochromium, permitted the use of low chromium-to-iron ratio ore for smelting to ferrochromium. The Republic of South Africa is the most abundant and low-cost source of such ore. Unfortunately, this ore is friable (breaks easily into small pieces), and the finer fractions of such ore are blown out of a furnace before it can be smelted. Agglomeration technology has been developed to permit the use of fine chromite ore in the

electric arc furnace. Both briquetting and pelletizing are practiced. Efficient production technology uses prerduced and preheated pelletized furnace feed. Industry is developing new production technologies using high-temperature plasmas or using alternatives to electrical power supply. The new production technologies are expected to be more cost competitive than traditional production technology under some conditions. Advanced smelting technologies that use abundant friable ore have been and are being developed. Plasma processes, including both transferred and nontransferred arc processes, have been applied to ferrochromium production. The kiln roasting prerduction process is being applied to ferrochromium production.

Recycling.—Recycling is the only domestic supply source of chromium. Stainless steel and superalloys are recycled, primarily for their nickel and chromium contents. As much as 50% of electric furnace stainless steel production can result from recycled (i.e., new and old) stainless steel scrap. Advanced stainless steel production technology like continuous casting reduces prompt scrap generation and permits a higher product yield per unit of raw material feed. See figure 2 depicting the general recycling of chromium material flow industry structure. (See figure 2.)

Byproducts and Coproducts

Chromite ore is mined as a primary product. Chromite is not a byproduct or coproduct of the mining of any mineral, nor are there byproducts or coproducts associated with chromite mining. Chromite has the potential of becoming a byproduct of platinum mining in the Republic of South Africa or of lateritic nickel mining. Platinum and chromite are both present in the UG2 seam of the Bushveld Complex in the Republic of South Africa. At present, most platinum mining is from the Merensky Reef. However, as platinum mining from the UG2 seam continues and as new mining operations that exploit the UG2 seam are

developed, chromite-containing tailings will continue to grow. The feasibility of utilizing these resources has been demonstrated, and new ferrochromium production facilities under development by Samancor Ltd. are designed to permit the use of these resources. It appears to be only a matter of time before economic conditions favor the use of those tailings, thereby making chromite a byproduct of some platinum operations.

Economic Factors

Prices.—Inadequate supplies of ferrochromium in the late 1980's resulted from strong demand for stainless steel in all three major producing regions: the United States, Japan, and Europe. This inadequate supply resulted in increasing ferrochromium prices until mid-1989, when supply exceeded demand and prices began to decline. In 1989 and 1990, new ferrochromium plants and plant expansions were under construction or being completed. Reduced stainless steel production permitted ferrochromium producers, traders, and consumers to rebuild stocks after about 3 years of generally increasing production. Reduced demand for ferrochromium, resulting from decreased stainless steel production, and increased supply of ferrochromium, resulting from producer expansions and new plant construction, have resulted in declining ferrochromium prices since 1990.

The historical value of chromite ore by grade, ferrochromium by grade, and chromium metal imported to the United States is shown in tables 4 and 5. These values show that as chromite ore is processed to ferrochromium and to chromium metal, the added value is quite large. On a per unit of contained chromium basis for recent years, the value of ferrochromium is about 5 times that of chromite ore; the value of chromium metal is about 30 times that of chromite ore. Variations of the value of ore are shown to follow those of ferrochromium, indicating values of chromite ore change in response to demand with ferrochromium value first to reflect demand changes.³ Ferrochromium

values show greater variation than those of chromite ore. The unit value of chromium materials has increased by 10% to 15% per year in actual value since 1963. (See tables 4 and 5.)

Costs.⁴—Operating and transportation are the two major components of chromite ore cost in the marketplace. Operating cost includes mining (the production of run-of-mine ore) and beneficiation (the production of marketable chromite ore or concentrate from the run-of-mine ore). Mining cost is typically in the range of 70% to 90% of operating cost but exceeds 90% in some cases. Labor cost is the major component of mining and of beneficiation cost. Labor cost is typically in the range of 20% to 70% of mining cost and from 25% to 90% of beneficiation cost, but can be higher.

Excluding the delivered cost of chromite ore, electrical energy, other raw materials, and labor are the major components of smelting (i.e., production of ferrochromium from chromite ore) cost. (Note that smelting cost excludes the cost of chromite ore feed material.) Electrical energy cost is in the range of 20% to 55% of smelting cost; raw materials (excluding chromite ore), 15% to 35%; and labor, 10% to 30%.

The U.S. Bureau of Mines has studied the availability of chromium. The Bureau analyzed the cost and availability of chromium materials. The chromium materials included exportable chromite products (metallurgical, chemical, refractory, and foundry sands) and chromium ferroalloy products in 10 market economy countries (MEC's). These various chromium materials were simultaneously analyzed for cost and availability. The product breakdown among chromium materials was based on mine and smelter production capacities and known operating relationships circa the 1987-88 time period.

A total of about 874 million tons, gross weight, of in situ material containing about 203 million tons of chromium was analyzed. Extraction and beneficiation of this material was estimated to yield about 475 million tons

of chromite products, of which 289 million tons would be available for export and the remaining 187 million tons would be smelted in the country in which it was mined to produce about 80 million tons of chromium ferroalloys. The chromium ferroalloys would then be available for use in the country of production or for export. The 80 million tons of chromium ferroalloys included about 74 million tons of high-carbon ferrochromium, 4 million tons of low-carbon ferrochromium, and 2 million tons of ferrochromium-silicon.

The countries of the Republic of South Africa and Zimbabwe contained about 80% of the in situ chromium contained in chromite ore. Finland and India accounted for an additional 11% of the contained chromium; another 8% of the contained chromium was fairly evenly split among Brazil, the Philippines, Turkey, and the United States; and the remainder was in Greece and Madagascar.

Based on Cr_2O_3 content of in situ chromite ore, the 10 MEC's split into 2 groups, a high-grade group and a low-grade group. The high-grade group, those with ore grades ranging from 34% to 43% Cr_2O_3 , included India, Madagascar, the Republic of South Africa, Turkey, and Zimbabwe. The low-grade group, those with ore grades ranging from 9% to 27% Cr_2O_3 , included Brazil, Finland, Greece, the Philippines, and the United States. The grade differences between the two groups resulted in a wide disparity in their respective weighted average Cr_2O_3 contents. The high-grade group averaged 39% Cr_2O_3 , and the low-grade group, only 16% Cr_2O_3 .

Table 6 shows the results of the Bureau's analysis. Chromium material costs were calculated on a weighted average basis, f.o.b. ship at the port of export. Chromite costs shown in table 6 include chromite ore mining and beneficiating (including mine capital and operating costs and taxes) and chromite product transportation to port facilities. Chromium ferroalloy costs include chromite ore but exclude smelter capital cost. On a weight basis, the Bureau's analysis shows that the Republic of South

Africa and Zimbabwe could produce about 78% of metallurgical chromite ore, 93% of chemical chromite ore, 85% of refractory chromite ore, and 93% of foundry chromite ore that could be produced at their respective estimated break-even cost. The Republic of South Africa and Zimbabwe could also produce about 69% of the high-carbon ferrochromium, 89% of the low-carbon ferrochromium, and 100% of ferrochromium-silicon that could be produced at their respective estimated break-even cost. (See table 6.)

The low-carbon ferrochromium availability curve is shown in figure 3; the high-carbon ferrochromium is shown in figure 4. The costs shown in figures 3 and 4 include mining and beneficiation operating and capital costs, transportation to specific smelters, smelting operating costs, taxes, and transport costs to specific port cities for export. Recovery of initial capital costs at the ferrochromium smelters has not been included. Figure 3 shows that the MEC's studied support total production of 4 million tons of low-carbon ferrochromium at a cost ranging from about \$0.42 to \$0.95 per pound, contained chromium, for 0% discounted cash-flow rate of return. Figure 4 shows that the same MEC's studied support total production of about 74 million tons of high-carbon ferrochromium at a cost of about \$0.28 to \$1.07 per pound, contained chromium, at a 0% discounted cash-flow rate of return. (See figures 3 and 4.)

Tariffs.—Import tariffs are typically imposed to protect the domestic industry. Where there is no domestic industry, such as chromite ore production in the United States, there is no tariff. (See Foreign Trade section of this report for U.S. tariff duties on chromium materials.) In some cases, such as ferrochromium imports to the European Community, import tariffs are used with import quotas. That is, a duty-free quota is allocated to member countries. The quotas may be revised as necessary to meet the needs of domestic consumers and producers. Only in a few cases, such as ferrochromium exports from China and certain grades of

chromite ore exports from India, are export duties applied.

Operating Factors

Environmental Requirements.—Chromium releases into the environment are regulated by the Environmental Protection Agency (EPA). Workplace exposure is regulated by the Occupational Safety and Health Administration.

Toxicity.⁵—The effect of an element on the human body depends on several factors. These factors include the chemical or class of chemical, the route of exposure, the quantity and duration of exposure, and characteristics of the exposed subject.

Human Toxicity.—The chemical distinctions typically made about chromium chemicals include whether the compound is synthetic or naturally occurring. Synthetic chromium compounds are typically classified by their oxidation state. Trivalent and hexavalent chromium compounds are two such classifications. Exposure to chromium compounds could typically occur through one or more of three routes: skin contact, ingestion, or inhalation. Exposure can also vary in intensity (concentration of the chemical) and duration (length of time for which exposure occurs). Response to chemical exposure is dependent on such human characteristics as age, sex, general health, and sensitivity. The effect of chemical exposure on the human body can be good or bad. Chromium is one of those elements that is both essential to good health and detrimental to good health. The detrimental effects of chemical exposure are classified as acutely toxic when small amounts of the chemical cause significant damage in a short time; chronically toxic when exposure over a long time causes measurable damage; and carcinogenic when exposure can result in cancer.

Background levels of chromium may be estimated from natural abundances. At about 185 parts per million, chromium

is the 13th most common element in the Earth's crust, and at 0.2 parts per billion, the 26th most common element in seawater.

Under some conditions chromium compounds cause systemic damage to the human body.⁶ Because experimentation on human subjects is morally unacceptable, most toxicity data results from workplace, coincidental, or accidental human exposure or animal experimentation. EPA concluded that there is sufficient evidence in animals and humans for the carcinogenicity of chromium (VI) compounds, while evidence for the carcinogenicity of chromium (III) compounds in humans and animals is largely nonpositive. The acute toxicity of chromium (III) compounds is low whereas the acute toxicity of chromium (VI) compounds is in the high to moderate range. Chronic toxicity of chromium (III) is considered low.

Chromium generally forms chemical compounds in which chromium has either the hexavalent or trivalent oxidation state. Hexavalent chromium compounds are generally recognized as toxic. Chronic occupational exposure to hexavalent chromium has been associated with an increased incidence of bronchial cancer. The toxic status of trivalent chromium compounds is not clear. However, trivalent chromium compounds are less toxic than hexavalent chromium compounds. Chemical compounds containing chromium in lower valence states are generally recognized as benign.

Human Health.—Chromium is a trace mineral required by the human body for good health.⁷ A daily intake in the range of 50 to 200 micrograms has been recommended. Chromium is a cofactor for insulin, a hormone that participates in carbohydrate and fat metabolism. A cofactor is a material that acts with the material. The dietary chemical compound form of chromium is trivalent. Because humans cannot convert trivalent (III) chromium to hexavalent (VI) chromium, the carcinogenicity of hexavalent chromium compounds bears no relevance to the nutritional role of trivalent chromium.

Environmental Releases and Transfers.⁸—The EPA regulates and monitors industrial impact on the environment. As part of its monitoring activity, EPA collects data on toxic chemicals. That information is made available in the Toxic Release Inventory (TRI). TRI is mandated under title III of the Superfund Amendments and Reauthorization Act (SARA) of 1986.

Chromium has been identified as a toxic material by the EPA. As a toxic material, companies that release chromium-containing materials into the environment are required to report those releases to EPA. In turn, EPA collates the reported information and makes it publicly available in the form of the TRI data base.

EPA has been collecting environmental release information since 1987 from manufacturing facilities that employ 10 or more persons and used a threshold amount of chromium contained in chromium compounds. (A manufacturing facility is one whose product is included in Standard Industrial Classification Division E (SIC) Codes 20 through 39. EPA does not cover Division B, Mining, Groups 10 through 14.) The threshold amount decreased from 1987 to 1989, after which time it remained constant. The threshold limit for a facility that manufactured or processed chromium compounds was about 34 tons of contained chromium in 1987, about 23 tons in 1988, and about 11 tons in 1989 and subsequent years. The threshold limit for facilities that otherwise used chromium compounds has been and remains about 5.4 tons. (Note that EPA has definitions for the terms manufacture, process, and otherwise use for the purpose of reporting releases.) When reporting chromium releases, a facility must add up the chromium released from all sources that exceed a de minimis amount. The de minimis amount for chromium compounds is 0.1%. Facilities report the amount of chromium released to the air, water, and earth environment; the amount of chromium recovered on site; and the amount transferred to offsite locations. The collected data are called the TRI.

EPA reported total releases and transfers of chromium in chromium and chromium compounds in 1987 to have been 41,362 tons; 1988, 56,051 tons; 1989, 51,894; and 1990, 35,129 tons. By materials destination, land releases and offsite transfers accounted for the largest share of reported releases and transfers. By reporting industry, chemical and allied products and primary metals industries accounted for the largest shares of releases.

Energy Requirements.—Electric arc furnace ferrochromium production is an electrical energy intensive process (requiring about 3,500 to 3,800 kilowatt-hours per ton of ferrochromium produced) that produces similar volumes of ferrochromium and slag. However, heat recovery can reduce energy requirements. Energy efficient processes using preheating can reduce the energy requirements to about 2,500 to 2,800 kilowatt-hours per ton of ferrochromium produced. Typically, all of the energy required to smelt chromite is supplied in the form of electricity. Electrical energy requirements can be reduced by preheating or prereducing charge material using alternative energy sources such as coal, natural gas, or fuel oil. Advanced production technology permits the use of liquid or gas fuel to substitute for part of the energy required. Alternative production technology is being developed that would permit nonelectrical energy sources to supply a significant fraction of the energy required to smelt chromite ore.

Transportation.—Chromite ore is typically transported by trackless truck or conveyor belt from the mine face to storage or processing facilities on the mine site. From there, it is transported by truck from the mine site to the local railhead. It is then transported by rail to ports or to smelters. Smelters that do not have associated loading and unloading facilities for ships transport their product by rail to ports. Following transport by ship to consumer countries, chromium materials are typically barged or hauled

by truck to end users who have no loading and unloading facilities for ships.

ANNUAL REVIEW

In 1991, chromium apparent consumption was about 366,000 tons of contained chromium. The reported consumption of chromite by the chemical and metallurgical industry and by the refractory industry decreased. Chemical and metallurgical industry chromite consumption includes material consumed as part of the NDS program to convert chromite ore to ferrochromium. Imports of chromite decreased as did chromium ferroalloys compared with those of 1990. (See table 7.)

U.S. supply consisted of recycled and imported chromium materials. The United States recycled about 540,000 tons, gross weight, of stainless steel scrap and imported about 641,000 tons of chromite ore, ferroalloys, chemicals, and pigments valued at about \$328 million. The United States exported about 87,000 tons of chromium materials valued at about \$56 million. In 1991, both quantity and value of imports of chromium materials decreased, and exports of chromium materials increased compared with those of 1990.

Legislation and Government Programs

The President terminated sanctions, implemented under the Comprehensive Anti-Apartheid Act of 1986 (Public Law 99-440), against the Republic of South Africa. In July, the President found that the Government of South Africa had taken all of the steps specified in section 311(a) of the act, and, therefore, that title III and sections 501(c) and 504(b) of the act had terminated. He ordered executive departments and agencies to terminate sanctions and revoked previous Executive orders regarding the sanctions effective July 10, 1991. As a critical and strategic material unavailable from other reliable suppliers, chromium materials were exempt from the sanctions against imports from South Africa.⁹

In accordance with the President's November 1982 directive and Public Law

99-591, the DLA continued to upgrade NDS chromite ore to high-carbon ferrochromium. The Agency reported conversion of chromite ore to ferrochromium on a calendar year contract basis. DLA signed a contract with Macalloy Corp., Charleston, SC, in 1990 to upgrade NDS chromite ore. The contract period covers the years 1990-94, the last 2 years of which are optional for DLA. (See table 8.)

As part of its plan to modernize the NDS, DLA contracted with Elkem Metals Co., Marietta, OH, to upgrade NDS nonspecification-grade low-carbon ferrochromium into electrolytic (vacuum melting-grade) chromium metal. Elkem converted low-carbon ferrochromium to chromium metal in 1989 and 1990. In 1991, DLA contracted with Elkem to convert low-carbon ferrochromium to about 1,100 tons of chromium metal. DLA also exercised its option to have Macalloy convert chromite ore to ferrochromium in 1992. (See table 9.)

EPA promulgated its final rule on chromium contained in primary drinking water. EPA set the maximum contaminant level goal (MCLG) and the maximum contaminant level for chromium contained in primary drinking water at 0.1 milligram per liter. EPA identified the best available technologies to remove chromium III compounds to be coagulation with filtration, ion exchange, lime softening, and reverse osmosis. EPA identified the best available technologies to remove chromium VI compounds to be coagulation with filtration, ion exchange, and reverse osmosis. EPA concluded that chromium contained in drinking water should be minimized in recognition of its biological reactivity, including its potential for being a carcinogenic hazard. EPA set the chromium III and chromium VI MCLG based on the reference dose concept. The safe dose to which EPA refers is the National Academy of Sciences recommended daily intake of 50 to 200 micrograms per day. EPA commented that should new data demonstrate a cancer risk by ingestion of chromium VI, it would reconsider the chromium VI MCLG.¹⁰

EPA denied a petition to remove chromium III compounds and chromic oxide in particular from the chemicals covered by the Emergency Planning and Community Right-to-Know Act of 1986, in particular from the section 313 list of toxic chemicals. The petition to remove chromium III compounds was based on the contention that chromium III compounds are considered nonhazardous wastes under the Resource Conservation and Recovery Act (RCRA). EPA denied the petition based on EPA's determination that the conversion of chromium III to chromium VI has been demonstrated to occur in soils and in water-treatment processes that use chlorine.¹¹

EPA announced that treated residue from roasting and leaching of chromite ore is to be regulated under section D of RCRA, its final rule on the regulation of this material. RCRA was amended in 1980 to exclude solid waste generated by the extraction, beneficiation, and processing of ores and minerals from being regulated as hazardous waste under subtitle C of RCRA until those wastes could be studied to determine the manner in which they should be regulated. EPA was directed in 1988 by a court order to restrict the scope of exclusion to large volume, low hazard waste. An EPA study determined that treated residue from roasting and leaching of chromite ore does not pose an actual or potential danger to human health and the environment. EPA therefore decided to regulate treated residue from roasting and leaching of chromite ore under section D of RCRA.¹²

EPA started the 33/50 Program, a voluntary program to reduce environmental release and transfer of 17 toxic chemicals, including chromium and chromium compounds. The program is so named because its objective is the voluntary one-third reduction of chromium and chromium compound releases and transfers by 1992 and one-half reduction by 1995. Reductions are to be measured against 1988 TRI data.¹³

Strategic Considerations

Supply Security.—There is no production of chromite ore in the United States; primary consumption of chromium by U.S. industry is by companies that use chromite ore to produce ferrochromium, chromium chemicals, and chromite refractories and by chromium metal producers that use ferrochromium. Chromite ore reserves are abundant, ensuring adequate long-term supply. However, supply sources are few and remote from the United States, making supply vulnerable to disruption. The problem for the United States is one of national security. Ferrochromium is essential to stainless and some alloy steel production, which are in turn essential to both the domestic economy and to the production of military hardware.

Stockpile.—The NDS contains the following chromium materials: chromite ore, chromium ferroalloys, and chromium metal. The purpose of the NDS is to supply military, essential civilian, and basic industrial needs of the United States during a national defense emergency; by law, the stockpile cannot be used for economic or budgetary purposes. In addition to private and Government stocks, there exists a large unreported inventory of chromium contained in products, trader stocks, and scrap. The amount of these stocks varies with demand and price of the material. Under severe price pressures resulting from primary chromium shortages, recycling of consumer materials could add to the supply.

Chromite ore must be converted to ferrochromium before it can be used to make steel. Prompt response during a national defense emergency requires that conversion be carried out by domestic industry. However, domestic ferrochromium production capacity is not adequate to meet anticipated domestic demand under mobilization conditions. To ensure prompt NDS response to a national defense emergency, the President chose to convert stockpiled chromite ore to ferrochromium. Changes in industrial

capacity and new manufacturing and technological developments have rendered selected chromium materials in the NDS inventory obsolete, either in quality or form or both, and in need of upgrading. Subsequent to legislative mandate, DLA began modernizing chromium materials in the NDS by converting nonspecification-grade low-carbon ferrochromium into chromium metal. (See Legislation and Government Programs section of this report.) (See table 10.)

Issues

World ferrochromium production capacity in 1991 significantly exceeded demand, resulting in low capacity utilization. Major restructuring of the chromium industry occurred in India and the Republic of South Africa. (See India and Republic of South Africa under World Review section of this report.) Strong demand for ferrochromium, resulting from high levels of stainless steel production worldwide in 1987-89, resulted in ferrochromium plant expansions and new plant construction. Since 1970, the trend has been for ferrochromium production capacity to move from major stainless steel-producing countries (e.g., Japan, the United States, and Western Europe) to major chromite ore-producing countries (e.g., Finland, the Philippines, the Republic of South Africa, Turkey, and Zimbabwe). This has occurred through the creation of new plants or furnaces in chromite ore-producing locations and the closure of furnaces in other geographic areas where ferrochromium production was formerly strong. The increase in and change in location of world annual gross weight production capacity has continued that trend. Most of the added capacity was in chromite ore-producing countries. All of the capacity contraction was in nonchromite-producing countries. The largest addition to national annual capacity was in the Republic of South Africa, increasing the Republic of South Africa's capacity by about 30% in the 1989-90 time period. The supply shortage in 1988 was estimated to have been about 200,000 tons or about 5% of

1988 world production capacity. The expansion of 1989 and 1990 represented about 16% of 1988 world production capacity.

Stainless steel is the major chromium end use. Despite strong stainless steel production in 1991, ferrochromium production capacity exceeded demand, and weak prices resulted. Ferrochromium producers limited production and planned plant closings to reduce supply of ferrochromium in the expectation that reduced supply would stimulate prices to increase.

With stainless steel production growing at a long-term average annual rate of 3% to 4%, it is estimated that it will take until 1995 (about 5 years of average industry performance) for demand to catch up with added capacity. Experience shows that short-term variations in chromium consumption and production can be significantly larger than long-term trends.

Production

The major marketplace chromium materials are chromite ore and chromium metal, ferroalloys, and chemicals. In 1991, the United States produced chromium metal, ferroalloys, and chemicals, but no chromite ore. (See tables 11 and 12.)

Chrome Corp. of America, a subsidiary of Boulder Gold (Australia), continued to study possibilities for the development of its chromite resources in Montana. Chrome Corp. reportedly studied the possibility of producing stainless steel using Montana chromite ore.

Macalloy Corp. converted chromite ore to high-carbon ferrochromium for the NDS under a contract with the DLA. Elkem Metals Co. converted nonspecification-grade low-carbon ferrochromium into chromium metal for the NDS under a contract with the DLA. (See Legislation and Government Programs section of this report.)

Macalloy planned to construct a plasma arc furnace in cooperation with the South Carolina Research Authority at a cost of about \$10 million. The new furnace was

planned to have a daily production capacity to about 60 tons and electrical capacity in the range of 7 to 25 megavolt-amperes. The furnace was planned to become operational in 1993.

Chromium chemicals industry and production capacity were reviewed. American Chrome and Chemicals produced sodium bichromate with an annual capacity of about 45,000 tons. Occidental Chemicals Corp. produced sodium bichromate with an annual sodium bichromate production capacity of about 103,000 tons.¹⁴ (See chromium chemicals under Outlook section of this report.)

Consumption and Uses

Domestic consumption of chromite ore and concentrate was 375,084 tons in 1991. Of the total chromite consumed, the chemical and metallurgical industry used 339,068 tons, and the refractory industry, 36,016. Much of the chromite consumed and ferrochromium produced by the metallurgical industry were part of the NDS conversion program. (See Legislation and Government Programs section of this report.)

Chromium has a wide range of uses in the three primary consumer groups. In the metallurgical industry, its principal use in 1991 was in stainless steel. Of the 367,220 tons of chromium ferroalloys, metal, and other chromium-containing materials reported consumed, stainless steel accounted for 80%; full-alloy steel, 7%; superalloys 3%; and other end uses, 10%. The primary use of chromium in the refractory industry was in the form of chromite to make refractory bricks to line metallurgical furnaces.

The chemical industry consumed chromite for manufacturing sodium bichromate, chromic acid, and other chromium chemicals and pigments. Sodium bichromate is the material from which a wide range of chromium chemicals are made. (See tables 13 and 14.)

Stocks

Reported consumer stocks of chromite in the United States decreased from 354,661 tons in 1990 to 321,225 tons in 1991. Chemical and metallurgical industry stocks decreased as did refractory industry stocks. At the 1991 annual rate of chromite consumption, consumer stocks represented about 11 months of supply in the chemical and metallurgical industry and 4 months of supply in the refractory industry. Producer stocks of chromium ferroalloys, metal, and other materials decreased from 14,935 tons in 1990 to 11,832 tons in 1991. Consumer stocks increased from 17,598 tons in 1990 to 18,772 tons in 1991. At the 1991 annual rate of chromium ferroalloy and metal consumption, producer plus consumer stocks represented about a 1-month supply. (See table 15.)

Prices

The price of chromite decreased steadily in 1991. The published price of the Republic of South African Transvaal chromite, 44% Cr₂O₃ (no specific chromium-to-iron ratio), decreased from a range of \$50 to \$55 per ton, f.o.b. the Republic of South African ports, to a range of \$42 to \$50 in August, where it remained for the rest of the year. The published price of Turkish ore changed from a range of \$120 to \$135 per ton, f.o.b. Turkish ports, to a range of \$130 to \$135 in February. It then decreased to a range of \$120 to \$130 in August, where it remained for the rest of the year.

Ferrochromium prices generally began the year in a decline and then increased toward midyear. The published price of domestic high-carbon ferrochromium (50% to 55% chromium) decreased from 54.5 to 49 cents per pound of chromium content (¢/lb-Cr) in August, where it remained for the rest of the year. The published price of domestic low-carbon [0.05% and 0.015% (Simplex) carbon] ferrochromium remained unchanged.

The published price of electrolytic chromium metal remained at 370 ¢/lb throughout the year. The price of

elchrome-grade electrolytic chromium metal increased from 422.5 ¢/lb to 450.0 ¢/lb in March, where it remained for the rest of the year. (Elchrome is a vacuum degassed chromium metal product produced by Elkem Metals Co.)

The published price of imported high-carbon (50% to 55% and 60% to 65% chromium) ferrochromium varied throughout the year. The published price of 50% to 55% high-carbon ferrochromium started at a range of from 46 to 47.5 ¢/lb-Cr and ended the year at 48 to 48.5 ¢/lb-Cr. The price varied frequently, especially at yearend. The published price of imported 60% to 65% high-carbon ferrochromium started the year at a range of 42.25 to 45.5 ¢/lb-Cr from which it increased to a high of 51 to 52 ¢/lb-Cr in March, after which it declined to a low of from 42.5 to 43.75 ¢/lb-Cr in September. The price then increased to a range of from 46.75 to 47.5 ¢/lb-Cr in December. The published price changed monthly. The published price of imported low-carbon (0.05% carbon) ferrochromium increased from a range of from 100 to 105 ¢/lb-Cr to a high of from 104 to 107 ¢/lb-Cr in April, after which it steadily declined to a low from 85 to 86.5 ¢/lb-Cr in December. (See table 16.)

Foreign Trade

Chromium material exports from and imports to the United States included chromite ore and chromium metal, ferroalloys, chemicals, and pigments. (See tables 17 through 22.)

World Review

Industry Structure.—The chromium industry is composed primarily of chromite ore producers, ferrochromium producers, and stainless steel producers. Other industry components are chromium chemical and chromite refractory producers. Brazil, Finland, India, the Republic of South Africa, and the U.S.S.R. are countries that mine chromite, produce ferrochromium, and produce stainless steel. In Finland, Outokumpu Oy, a major share of which

is state-owned, owns and operates chromite mining, ferrochromium production, and stainless steel production facilities, making it completely vertically integrated. In the Republic of South Africa, major restructuring occurred. (See Republic of South Africa section.) Samancor is vertically integrated from chromite mining through ferrochromium and stainless steel production. Consolidated Metallurgical Industries and Chromecorp Technology are vertically integrated from chromite mining through ferrochromium production. Chromium-related companies in the Republic of South Africa are privately owned. Typically, major shares of a company are owned by other companies, and the remainder, if any, is openly traded. In Brazil, the mining and smelting of chromium is vertically integrated, but stainless steel production is independent of the mining-smelting operations. The major mining companies are subsidiaries of Cia. de Ferro Ligas da Bahia S.A. Stainless steel is produced primarily by Companhia Aços Especiais Itabira. Other chromite operations in Brazil are also vertically integrated. Bayer AG (Federal Republic of Germany) owns a chromite mine and chromium chemical plant. Refractory chromite operations are also vertically integrated from chromite production through refractory material production. Chromite mining and ferrochromium production in India is mostly vertically integrated. Ferro Alloys Corp. is the only stainless steel producer in India that is integrated from chromite ore mining through ferrochromium and stainless steel production. In the former U.S.S.R., chromite mining, ferrochromium production, and stainless steel production were state-owned.

The chromium industry of Japan consists primarily of the production of ferrochromium and stainless steel. Chromite ore production in Japan is small relative to consumption. In Japan, industrial companies may group together to meet common needs such as insurance, banking, transportation, international trade, real estate, etc. Companies within a group are frequently part owners of other companies within the group, but

share holding between groups is also common, especially by banking and trust companies. The Japanese ferrochromium producers are typically associated with stainless steel producers and may be part of a group. Association means the stainless steel producer takes the output of the ferrochromium producer. Because Japanese industry is typically both forward and backward integrated, stainless steel and ferrochromium producers may each be partial owners of one another. (See figure 5.)

The chromium industry of Turkey is composed of both large and small chromite ore producers, with one major producer, Etibank, integrated from mining through ferrochromium production. The chromium industry of Zimbabwe is composed of large companies vertically integrated from chromite mine production through ferrochromium production, small independent chromite mines, and chromite mines operated independently on behalf of the large vertically integrated companies.

Capacity.—The data in table 23 are rated capacities for major countries that mine chromite ore and produce ferrochromium, primary chromium chemicals, and chromium metal as of December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time at a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. Because not all countries or producers make production capacity information available, historical chromium trade data have been used to estimate production capacity. Rated production capacity changes result both from changes in facilities and changes in knowledge about facilities.

Reserves.—The United States has no chromite ore reserves. However, the United States has a reserve base and resources that could be exploited. (For further information on domestic reserves, reserve base, and resources, see Geology-Resources section of this report.) (See table 23.)

Albania.—Eight chromite ore-producing mines were reported operating. The mines and the districts in which they are located were: Kam in Tropojë, Vlahne and Kalimash in Kukës, Bulqize and Ternove in Peshkopi, Bater in Mat, Katjel in Librazhd, and Pojske in Pogradec. Production and exports by grade were reported and are shown in table 24.

The Bulqize Mine was mechanizing its ore transport in the process of increasing production capacity from 200,000 to 300,000 tons per year. Chromite reserves in the Kukës region were estimated at 14 million tons.

Civil unrest and some chromite ore mine strikes were reported. Albania reported its intention to develop its chromium industry—chromite ore and ferrochromium production. The European Community, Union Carbide (United States), and Samancor (South Africa) were involved in development discussions at various times during the year. No specific development arrangement had been made by yearend. Electrical energy availability that has limited ferrochromium production in the past was not a problem. Hydroelectric power was sufficiently abundant to have been exported. (See table 24.)

Australia.—Australia reported its demonstrated, subeconomic resources of chromite ore to have been 2.37 million tons of paramarginal and 0.52 million tons of submarginal resources and inferred, subeconomic resources to have been 20 million tons.

The Coobina chromite deposit was reviewed. The deposit, in Western Australia (23°29'S latitude, 120°16'E longitude), was found to have a chromite reserve base of about 124,000 tons

graded at 39.3% Cr₂O₃. It was reported that surface mining between 1950 and 1957 resulted in the production of 14,610 tons of ore that was used to produce refractories after smelting tests proved unsuccessful. More recent analysis of the ore showed that crushing and gravity separation of run-of-mine ore could produce metallurgical-grade (43% Cr₂O₃, Cr:Fe=1.6, lumpy) and chemical-grade (46% Cr₂O₃, fines) products. The economics of production (i.e., the price of chromite ore relative to the cost of selective mining, beneficiation, and transportation) was not good enough to choose mine development at the time of the evaluation.¹⁵

Brazil.—Brazil started a new economic plan in February. The new plan calls for a 75.45% increase of electric utility rates, increasing rates for ferrochromium producers from a range of 15 to 16 (US)mills per kilowatt-hour to a range of 26 to 27 (US)mills per kilowatt-hour. An antidumping case was filed against imports of ferrochromium from Albania, Greece, Turkey, and the U.S.S.R. At yearend, a decision had not yet been made.

Brazil received a \$62,000 contract through the International Development Fund of the United Nations Industrial Development Organization to treat tannery waste and to set up a specialized pollution control laboratory and training program. Recycling and recovery of chromium tanning material was one of the program objectives to reduce pollution in Franca, São Paulo State, where 4,500 to 12,000 hides were being processed daily with the expectation of tripling that rate.

Associação Brasileira Dos Produtores de Ferroligas (ABRAFE), the Brazilian ferroalloy producers association, reported 1991 production as follows: high-carbon ferrochromium, 74,788 tons; low-carbon ferrochromium, 7,437 tons; and ferrochromium-silicon, 4,524 tons. ABRAFE reported 1991 exports as follows: high-carbon ferrochromium, 27,015 tons; low-carbon ferrochromium, 20 tons; and ferrochromium-silicon, none. ABRAFE reported Brazilian

chromium ferroalloy production capacity to have been 120,000 tons of high-carbon ferrochromium, 14,000 tons of low-carbon ferrochromium, and 10,000 tons of ferrochromium-silicon. Brazilian chromium ferroalloy production capacity totaled 144,000 tons with production at 86,749 tons, giving a capacity utilization of 60% in 1991.

Cia. de Ferro Ligas da Bahia S.A. reported idling one of six high-carbon ferrochromium and one of three low-carbon ferrochromium furnaces owing to reduced demand.

Companhia Ferroligas do Amapá's Vila Nova Mine produced chromite in Amapá Territory. The Vila Nova Mine estimated its inferred chromite reserves at 7 million tons. Chromite production capacity was 50,000 to 60,000 tons per year of beneficiated product. The company started up a new beneficiation plant. The new plant was expected to reach full production capacity of 120,000 tons per year in 1992.

Companhia Ferroligas do Amapá (CFA) converted its furnaces to ferromanganese production in late 1990 because of the low ferrochromium price. CFA did not restart ferrochromium production in 1991.

Canada.—Canada studied its chromite occurrences in British Columbia. Geographic location of chromite occurrences were reported along with geology, mineralization, history, and current claims where possible.¹⁶

Sherwood Metallurgical Corp. continued development of a Canadian-based low-carbon ferrochromium smelter. The plant was planned to have an initial production capacity of 30,000 tons per year of low-carbon ferrochromium containing 60% to 65% chromium. Producing at full capacity, the plant was planned to annually consume 300,000 megawatt-hours of energy, 61,000 tons of chromite ore, 12,500 tons of low-sulfur reductant, and 22,000 tons of low-lime silica sand. The project was reported to have been seeking financing and a location.

China.—China reported chromite ore imports of 544,648 tons in 1991 (641,267 tons in 1990 and 700,076 tons in 1989). China imported chromite ore as feed material for its ferrochromium production industry. Ferrochromium producers included Hunan Ferro Alloy Works (Hunan Province), Jiangyang Ferro Alloy Works (Jiangsu Province), Jilin Ferro Alloy Works (Jilin Province), Liaoyang Ferro Alloy Works (Liaoning Province), and Shanghai Ferro Alloy Works.

European Community.—In 1990, the European Commission (EC) started an investigation when European ferrochromium producers requested them to investigate U.S.S.R. and Albanian high-carbon ferrochromium imports to determine whether or not the ferrochromium was being dumped in the European Community. The EC reportedly terminated its investigation in April after European producers did not respond in writing to an EC request for information. The EC set duty-free quotas for ferrochromium at 28,100 tons, the same as 1990 quotas.

The transition of the U.S.S.R. from a centrally planned economy starting in 1990 and the transition of the Soviet Union to independent States at the end of 1991, along with European commitment to assist the Eastern bloc countries and the former U.S.S.R. countries, posed a difficult problem for the European Community. Owing to high levels of stainless steel production in the 1989-90 time period, ferrochromium experienced short supply, resulting in production capacity expansions worldwide. Thus, former Eastern bloc and Soviet ferrochromium producers entered the European market at a time of excess supply, competing with European producers. The U.S.S.R. was thought to export about 40% of its ferrochromium production to European markets before 1989. Complicating this situation was the decline in production in the former Soviet States, resulting in their seeking external markets for even more ferrochromium than in previous years.

Finland.—Outokumpu Steel Oy planned to dredge port facilities at Kemi, the port through which it exports ferrochromium produced at its Tornio works, to permit larger volume vessels to use the port.

Greece.—Hellenic Ferroalloys SA (HFA) purchased the Domokos Mine from Financial-Mining Industrial and Shipping Corp. (FIMISCO), a Greek refractory producer. The mine has been producing refractory-grade chromite ore since World War II. Output from this mine was expected to eliminate HFA's need to import Albanian and Turkish chromite. The mine was reported to have reserves of 2 million tons and to have a production capacity of 100,000 tons per year. HFA's power supply was stopped in June by the Public Power Corp. While shut down, HFA relined its furnaces in June, and the Greek Government decided to liquidate the company in September, at which time the plant was closed. Ferrochromium production in 1991 was estimated at about 25,000 tons.

India.—National.—The Indian Government devalued the Indian Rupee to encourage foreign trade. The devaluation was expected to make ferrochromium production profitable which would, in turn, stimulate ferrochromium exports. The devaluation was about 20%.

Chromite Ore.—Industrial Minerals & Ferro Alloys Ltd. reportedly developed its chromite ore mining resources in the Boula region by leasing about 400,000 square meters of mining property from Serajuddin and Co.

Ferrochromium.—Ferro Alloys Corp. (FACOR) commissioned a captive electrical power generating facility (including a fuel oil storage facility) at its ferrochromium plant at Shreeramnagar in Andhra Pradesh State. The electrical powerplant consisted of three 10.5-megawatt diesel powered electrical generators. This captive power station is capable of supplying about one-half of FACOR's needs at Shreeramnagar.

FACOR continued construction of two 10.5-megawatt electrical generators at its charge-grade ferrochromium plant in Orissa State. This fuel oil fired powerplant has the capacity for addition of a third generator.

Indian Charge Chrome Ltd., a subsidiary of Indian Metals and Ferro Alloys Ltd., experienced transformer failures at its two captive power generators (108-megawatts total capacity) causing temporary reduction in production rate.

Ispat Alloys Ltd. planned to construct a ferrochromium plant in Dhenkanal District of Orissa State. Ispat planned to complete construction of the ferrochromium plant along with a captive powerplant in 1993.

Jindal Ferro Alloys obtained financing for and planned the expansion of its current production facilities estimated to have a capacity of about 6,000 tons per year. Jindal planned to construct crushing and grinding operations followed by kiln roasting and smelting in a 12-megavolt-ampere electric furnace having a production capacity of about 15,000 tons per year. Jindal planned to convert the existing furnace to low-carbon ferrochromium production.

Mandsaur Ferro Alloys sought capital investment to set up a high-carbon ferrochromium production facility in Madhya Pradesh. Capacity was to be about 6,000 tons per year. Nav Bharat Ferro Alloys converted one of its three 16.5-megavolt-ampere ferrosilicon furnaces to ferrochromium production, giving itself an estimated annual ferrochromium production capacity of about 20,000 tons per year. Sarada Ferro Alloys sought financing to add 5,000 tons per year of high-carbon ferrochromium production capacity to its current 6,000 tons per year at Srikakulam, Andhra Pradesh. Standard Ferro Chrome planned to expand its ferrochromium production capacity by 1995, based on an agreement with Tata Iron & Steel Co.

Tata Iron and Steel Co. entered the ferrochromium markets in 1990 with the acquisition of Andhra Ferro Alloys, Vizianagaram District, Andhra Pradesh State, and the conversion of part of Joda

Ferro Alloys, Kendujhar District, Orissa State, from ferromanganese production capacity to ferrochromium production capacity. Andhra provided capacity of about 5,000 tons per year, and the conversion of one of Joda's 9-megavolt-ampere ferromanganese furnace to a 12-megavolt-ampere ferrochromium furnace by Elkem (Norway) yielded about another 20,000 tons per year. Tata started marketing ferrochromium produced for itself on a conversion basis by Indian Charge Chrome Ltd. (ICCL), which provided Tata an effective additional ferrochromium production capacity of about 20,000 tons per year. ICCL, an export-oriented subsidiary of Indian Metals and Ferro Alloys, has a production capacity of about 50,000 tons per year. In 1991, Tata purchased OMC Alloys from Orissa Mining Corp., adding about another 50,000 tons per year to its capacity. Tata further made marketing agreements with Saida (about 11,000 tons per year of capacity), Standard Ferro Chrome (about 1,500 tons per year of current capacity and planned expansion to 120,000 tons per year), Nav Bharat Ferro Alloys (15,000 tons per year of capacity), and VBC Ferro Alloys (about 15,000 tons per year of capacity). Tata has thus, over a period of about 2 years, acquired an annual production capacity of about 140,000 tons to make it the largest single ferrochromium producer in India and of major size by world standards. This status will last as long as the conversion contracts, about 5 years, if Tata does not extend them or acquire production facilities. Tata holds the largest share of chromite ore reserves in Orissa. It has mechanized its Sukinda Chromite Mine and added a beneficiation plant, increasing production capacity to about 750,000 tons per year. Tata's moves into the ferrochromium market thus provide demand for its chromite ore production and take advantage of its existing public-sector marketing expertise.

Unimetal Alloys, a steel producer, sought financing to establish a ferrochromium plant at Hyderabad, Andhra Pradesh, to produce 60% to 65% and 70% to 75% high-carbon ferrochromium with chromite ore from

Orissa. Unimetal planned an annual capacity of about 25,000 tons from one 16.5-megavolt-ampere furnace, to be in production in 1994. VBC Ferro Alloys converted one furnace from ferrosilicon to ferrochromium to do toll conversion for Tata Iron and Steel Co. The conversion gave VBC an annual ferrochromium production capacity of about 20,000 tons for use against the 5-year conversion agreement with Tata. VBC planned to acquire a second furnace for the production of ferrochromium. When the new furnace is commissioned, the old furnace was planned to be converted back to ferrosilicon production.

Chromium Chemicals.—India supports an old and currently growing leather tanning industry. About 2,000 tanneries have the capacity to process 500,000 tons of hides and skins annually, and 80% of the tanneries use a tanning process that utilized basic chromium sulfate (BCS). India consumes about 25,000 tons of BCS annually for tanning, of which about 15,000 tons is absorbed in the hides and skins and 10,000 tons is discharged to wastewater.

Iran.—Faryab Mining and Chrome Smelting Co., a state-owned company, was producing chromite ore graded at 46% to 52% Cr₂O₃ and chromium-to-iron ratio of 3:1 at the rate of about 100,000 tons per year. Faryab started construction of a ferrochromium smelter consisting of two Chinese-made electric furnaces each with 15-megavolt-ampere electrical capacity and combined production capacity of 14,000 tons per year.

Italy.—Ferroleghé SpA was sold by Montedison SpA to Finanziaria Metallurgica, a member of the Indel Group. Ferroleghé operates three 12-megavolt-ampere furnaces with annual production capacity of 38,000 to 40,000 tons at its Milan plant. Ferroleghé has not been producing since 1990, but plans to restart production in 1992 using ore supplied by Albania, Turkey, and the former U.S.S.R. Ferroleghé is now

owned 98% by Indel and 2% by Finanziaria Metallurgica. Italcromo, a major shareholder of which is Finanziaria Metallurgica, continued construction of a ferrochromium plant at Termoli. Italcromo planned to install two furnaces, one in 1992 and a second in 1993, with a total annual production capacity of 100,000 tons of ferrochromium. Acciaierie e Ferriere Lombarde Falck SpA stopped production in January owing to weak market conditions and then resumed in July to take advantage of low-cost summer season electrical energy rates. Falck produces low-carbon ferrochromium at Novate Mezzola with an annual capacity of about 13,000 tons. Falck negotiated with SA des Minerais (Luxembourg) and Consolidated Metallurgical Industries (CMI) (Republic of South Africa) to restructure its production facilities. CMI was to provide technological consultation, and Minerais was to provide cash and marketing expertise.

Japan.—Japan operated a two-part stockpiling program, Government and private. Japan's goal was to acquire a stockpile of chromium materials adequate to serve the needs of Japanese industry for 60 days. Japan planned to have the Government finance and stockpile 70% of the material; and the private sector the remaining 30%. Metal Mining Agency of Japan, under the supervision of the Ministry of International Trade and Industry, operated the Government stockpile, while Japan Rare Metals Stockpiling Association operated the private stockpile. Japan planned to purchase about 2,000 tons of ferrochromium (1,500 tons high-carbon ferrochromium, 500 tons low-carbon ferrochromium) for its stockpile by March 1992. These purchases were expected to increase the stockpile quantities to the equivalent of 32.72 days of Japanese consumption. Japan planned to sell stockpiled materials up to 20% of holdings during price surges then to use the profits to finance additional purchases. Japan also planned to change the basis of estimating equivalent days of consumption from 1986 consumption to

an average of consumption over the 1986-90 time period.

Japan Metals and Chemicals Co. (JMC) closed one of three furnaces at its Oguni ferrochromium plant. The closure reduced the plant's annual production capacity from about 24,000 tons to about 15,000 tons. JMC's Kyushu plant was unaffected and continued to operate with an annual capacity of about 70,000 tons. Pacific Metals upgraded and increased the production capacity of its rotary kiln to match the capacity of its furnaces.

Japan reported stainless steel production of 2,839,472 tons in 1991, an increase of 6.8% compared with that of 1990. Japan's ferroalloy industry produced about 301,706 tons of ferrochromium, a decline of 7.5% compared with that of 1990. Japan's ferrochromium production has ranged from 260,000 tons to 360,000 tons per year in the 1980-91 time period. Japan imported 578,073 tons of ferrochromium in 1991, while it exported 1,928 tons, giving imports a 66% market share. Japan imported 755,059 tons of chromite ore and 794 tons of chromium metal.

Korea, Republic of.—Consumption of ferrochromium in 1991 exceeded that of 1990 by 40%, an increase that reflected growth of the Korean stainless steel production industry. (See table 25.)

Madagascar.—Kraomita Malagasy (Kraoma) mined 122,276 tons of chromite ore in 1990. Madagascar exported 79,269 tons of chromite in 1990. Beneficiation changes for Andriamena Mine chromite have enabled Kraoma to produce a chromite graded at 0.002% to 0.003% phosphorous, an improvement over the typical chromite grade of 0.007% phosphorous.

Norway.—Elkem Rana AS, a subsidiary of Elkem AS (Norway), started ferrochromium production from a second electric furnace. The furnace started this year is the same as the one started last year. Each furnace has an annual production capacity of about 70,000, giving Elkem Rana a total annual

high-carbon ferrochromium production capacity of 140,000. Elkem Rana's high-carbon ferrochromium production was estimated at 35,000 tons in 1990, 90,000 tons in 1991, and was projected to reach 140,000 tons in 1992. Elkem Rana has two more smelting furnaces at its Mo-i-Rana plant site that have not yet been dedicated to ferroalloy production.

Oman.—Oman planned the formation of a private company to exploit its chromite resources. Oman reported 425 deposits, one-half of which were in the Al Batinah, Ash Sharqiyah, and Az Zahirah regions. Oman did not produce chromite in 1991, but exported 12,500 tons from stocks.

Pakistan.—North West Frontier Province auctioned 5,000 acres in the Kohistan district. Leases were for a 5-year period and are renewable. The area was thought to have chromite deposit potential.

Philippines.—National.—The National Power Corp. of the Philippines reported the worst drought conditions since 1983. As a result of the drought, water levels were low and hydroelectric power use had to be curtailed early in the 1991 dry season (March through May). Water levels are typically restored during the rainy season, which starts in July. Rain volume was inadequate to restore water reserves, so power limitations were expected again at yearend. About 93% of Mindanao Island power supply is hydroelectric generated from water stored in Lake Lanao.

The National Resources Development Corp. (Philippine Government) started a program to make safety equipment available to small-scale mining operations on Dinagat Island through Government recognized miners' associations. The program was initially funded with \$10,500.

Chromite Ore.—Benguet Corp. agreed with the Department of Environment and Natural Resources (Philippine Government) and Consolidated Mines

(owners) to mine three refractory-grade chromite deposits on 616.12 hectares in Zambales Province, Luzon Island, at an annual production rate of about 60,000 tons. The mineral production-sharing agreement between the Government and Benguet entitles the Government to 1% of gross mining revenue in addition to a 5% excise tax, an annual occupation tax of \$3.75 per hectare, and 12.5% of net revenue at the start of commercial operations. Reserves were estimated to have been equivalent to about 25 to 30 years of production. Benguet already contracts with Consolidated to operate the Masinloc deposit in the same area. However, the Masinloc Mine was closed owing to financial difficulties of Consolidated Mines, its owner. The Securities and Exchange Commission (Philippine Government) authorized Consolidated to plan to reopen the Masinloc Mine. Plans must be agreed to by creditors, some of whom object to reorganizing. CPO Mineral Resources and Development Corp. received approval from the Board of Investment (Philippine Government) to invest \$600,000 to develop a chromite deposit on a 972-hectare site in Bukidnon Province, Mindanao Island. CPO planned to start production in 1992 at the rate of 36,000 tons per year and to increase the production rate to 60,000 tons per year after 5 years.

Ferrochromium.—Ferrochrome Philippines Inc., after closure in November 1990 over a power supply dispute, relined its furnace, repaired the furnace electrodes and roof, and repaired its pelletizing plant. The smelter restarted production in October only to face power cutbacks, then closure because of inadequate power supply.

Following damage to its furnace that caused plant closure in June, Integrated Chrome Corp. retained Nippon Denko (Japan) to plan plant expansion to coincide with plant repair. The damaged furnace was designed for ferrosilicon production. However, it had been converted to ferrochromium production. It had an electrical capacity of 20 megavolt-amperes and a production

capacity of about 24,000 tons per year of high-carbon ferrochromium.

Metro Alloys constructed a ferrochromium furnace. The furnace was being constructed by China Metallurgical Consulting Corp. and was planned to be completed in 1992. The furnace was planned to have an electrical capacity of 12.5 megavolt-amperes and a high-carbon ferrochromium production capacity of 30,000 tons per year.

Poland.—Poland introduced a 15% tariff on imported ferrochromium. The Laziska ferroalloy plant planned to start producing high-carbon ferrochromium in 1992.

South Africa, Republic of.—Major restructuring occurred in the South African chromium industry in 1991. The high price of ferrochromium in 1988-89 that resulted from stainless steel demand that could not be met by existing ferrochromium producers put working capital in the producers' hands. These high prices stimulated investment in new ferrochromium plants and equipment. In 1990, existing ferrochromium producers increased their production capacity by acquiring smaller producers or by expanding their production facilities. At this time, CMI added a furnace and acquired Purity Ferrochrome, a new producer; Samancor added furnaces at its Tubatse smelter; MS&A constructed a new ferrochromium production facility that uses a new production process (kiln furnace prereduction followed by electric furnace smelting) at Middelburg and increased the transformer capacity of its direct current transferred plasma arc furnace at Krugersdorp; and Chromecorp Technology added a furnace. (Ferroalloys made no changes.) During and following the introduction of this new ferrochromium production capacity in South Africa and other capacity around the world, ferrochromium supply exceeded demand, causing ferrochromium prices to decline.

With annual ferrochromium production capacity of almost 1.5 million tons (gross weight) per year, nearly one-third of

world ferrochromium production capacity, South Africa is greatly impacted by these changes. Ferrochromium accounts for nearly one-half of South African ferroalloy export earnings, and ferroalloys are about the third largest export earner following gold and coal. Ferroalloy export earnings of South Africa about equal those of platinum-group metals.

By yearend 1990, South African ferrochromium producers ranked, by production capacity, as follows: Samancor, 620 thousand metric tons, gross weight, per year (kt/yr); MS&A, 380 kt/yr; CMI, 320 kt/yr; CCT, 180 kt/yr; and Ferroalloys, 100 kt/yr. In 1991, Samancor acquired MS&A, increasing its capacity to about 1 million tons per year. MS&A, South Africa's only stainless steel producer, also sold its stainless steel operation, MS&A Stainless (previously Southern Cross Steel), with an annual production capacity of 120 kt/yr, to Columbus, a joint venture between Samancor and Highveld Steel and Vanadium (an Anglo American company). Columbus plans to increase its stainless steel production to about 400 kt/yr, putting them in the production range of current major world stainless producers in the Federal Republic of Germany, France, Japan, and the United States. Samancor also acquired the chromite ore mining operations of Rand Mines. (Both MS&A and Rand Mines were subsidiary companies of Barlow Rand.) The addition of Rand Mines' chromite ore mining annual capacity of about 1,700 kt/yr to Samancor's previous annual capacity of about 2,200 kt/yr gives Samancor the current annual chromite ore production capacity of about 4,000 kt/yr or nearly one-third of world annual production.

South Africa's Minerals Bureau reported 1990 chromite ore production (excluding Bophuthatswana) at 4,081,248 tons, a decrease of 4.5% over that of 1989. The Minerals Bureau reported 1990 chromite ore sales to have been as follows: domestic, 2,463,000 (down 3% from that of 1989); and foreign, 1,096,000 tons (down 20% from that of 1990). The Minerals Bureau reported

1990 chromium ferroalloy production at 1,022,026 tons, a decrease of 1.2% from that of 1989. The Minerals Bureau reported 1990 sales to have been as follows: domestic, 26,080 tons (down 57% from that of 1989); and foreign, 923,934 (down 2.8% from that of 1989). The large decreases in reported 1990 export sales of chromite ore and ferrochromium reflect lower consumer demand and world excess supply relative to demand.

Chromite Ore.—Weak demand for chromite ore in 1991 made economic chromite production for small- and medium-size mines difficult. Some closures were anticipated if demand continued to be weak. As indicated by reported sales aforementioned, about two-thirds of chromite production is consumed internally, mostly for ferrochromium production. Major chromite ore producers are associated with ferrochromium producers.

Chromium Chemicals.—Chrome Chemicals Ltd., a subsidiary of Bayer AG (Federal Republic of Germany), closed its chromium chemical production facility in Durban, Natal. Production reportedly was stopped because of weak demand and low prices worldwide.

Ferrochromium.—Chromecorp Technology (CCT) operated one ferrochromium plant at Rustenburg with an annual ferrochromium production capacity of about 150,000 to 180,000 tons from three electric furnaces. CCT planned the installation of equipment to recover chromium from slag and to install a fourth furnace for which floor space was provided during original plant construction. Slag beneficiation equipment was planned to be operational in 1992 and to provide a production capacity of about 16,200 tons per year. CCT also operated a captive chromite mine, the Chroombronne Mine. CCT planned to start up a new chromite mine with annual production capacity of about 250,000 tons to meet projected demand of its planned fourth furnace. Weak market conditions lead CCT to plan the

temporary closure of its furnaces at yearend.

Consolidated Metallurgical Industries Ltd. (CMI), a subsidiary of Johannesburg Consolidated Investment Co. Ltd., operated two ferrochromium plants: CMI at Lydenburg with about 210,000 tons annual production capacity and Purity at Rustenburg with about 120,000 tons annual production capacity. CMI also operated Purity Chrome Mine, a captive chromite mine associated with its Rustenburg plant. CMI experienced a brief labor strike in October, which was settled through a negotiated pay increase. CMI negotiated with CCT for the purchase of CCT. No purchase agreement was reached. CMI planned to close one furnace at Lydenburg and one at Rustenburg owing to weak demand.

Feralloys, a subsidiary of Associated Manganese Mines of South Africa, operated a ferrochromium plant at Machadodorp with annual production capacity of about 100,000 tons. The plant experienced a brief labor strike in September.

Samancor operated five ferrochromium plants: Batlhako with an annual production capacity of about 20,000 tons; Ferrometals at Witbank with an annual production capacity of about 300,000 tons; Tubatse at Steelpoort with an annual production capacity of about 300,000 tons; Middelburg plant at Middelburg with an annual capacity of about 280,000 tons (including the yet to go into commercial production kiln process); and Krugersdorp plant at Krugersdorp with an annual capacity of about 100,000 tons. Samancor has a total ferrochromium production capacity of about 1,000,000 tons. Owing to weak demand, Samancor reduced its production by closing some furnaces. Samancor planned further closures in 1992 should demand not improve. Samancor planned to improve energy efficiency of its transferred arc furnace at Krugersdorp by improving heat recovery. Samancor planned to restart the kiln at Middelburg after pollution control equipment was repaired and market conditions improved.

Sentrachem, previously a calcium carbide producer, planned to convert its

30-megavolt-ampere furnace to charge-grade ferrochromium production with annual capacity of 60,000 to 70,000 tons at a cost of \$10 million. The conversion was planned to be completed in 1992.

Spain.—Ferroaleaciones Españoles (Fesa) produced ferrochromium at its Medina del Campo plant, Valladolid, with an annual production capacity of about 32,000 tons. Electrical power cost and availability limited production. The plant ceased ferrochromium production in August of 1991 owing to high power cost. Fesa planned to continue ferrochromium production by recovering ferrochromium from stockpiled slag and to review its ferrochromium production decision in 1993, when it was anticipated that countries of the European Community would be exchanging electrical energy without tax, thereby reducing electrical energy cost to Fesa. Fesa was granted legal protection in September covering a 3-year period, during which the company planned to restructure.

Swaziland.—Australian Overseas Mining Ltd. (Australia) (AOM) has been planning to construct a smelter with production capacity of about 120,000 tons per year. AOM holds interest in the joint venture and manages the project. In 1991, AOM planned to construct the plant near the Emaswati coal mine. The plant was planned to use the CODIR production process developed by Krupp (Germany) for application to ferrochromium production, currently owned by Mannesmann Demag (Germany) and implemented by Middelburg Steel & Alloy (South Africa) (MS&A). AOM planned to start construction after Demag evaluated the operation of the MS&A plant. The project may be delayed because Samancor (South Africa), the new owner of MS&A, postponed startup of the new MS&A plant owing to excess world ferrochromium production capacity.

Sweden.—Vargön Alloys AB produced ferrochromium from chromite ore

supplied by Brazil, India, the Philippines, Turkey, the United States, and the U.S.S.R. Vargön produced high-carbon ferrochromium from three furnaces with an annual production capacity of about 155,000 tons. Vargön was founded in 1874 under the name Wargön Alloys as part of an agricultural-industrial complex. Airco (United States) acquired the complex in 1968, retaining only the ferroalloy division. Airco sold the complex to Fides (a subsidiary of Credit Suisse, Switzerland) in 1979, which subsequently sold it to a consortium of management and Mellanfonden (Sweden) in 1987. Vargön produces high-carbon ferrochromium graded at 4% to 6% carbon and 58% to 59% chromium.

Turkey.—Etibank completed construction of two new furnaces in 1989. One of those furnaces was started up that year and achieved production status in 1990. The second furnace was then started up on a trial basis. Etibank operated two smelters in 1991, one producing low-carbon ferrochromium at Antalya, with annual production capacity of about 10,000 tons, and one producing high-carbon ferrochromium at Elazığ, with annual production capacity of about 150,000 tons. Etibank petitioned the U.S. Trade Representative to make low- and high-carbon ferrochromium eligible for duty-free treatment. A decision was expected in 1992.

U.S.S.R.—In an effort to become better known in the West and following common practice among market economy businesses, the former planned economy country industries have made information about their operations known to the West through publicly available industry reports and news services. Through these reports and direct interaction among industry, government, and news reporting representatives, information about chromium-related industry in the former U.S.S.R. is becoming better known in the West. The chromium industry of the former U.S.S.R. that is currently actively interacting with the West includes

producers of chromite ore and chromium ferroalloys and metal.

Chromite ore and chromium ferroalloy and metal producers in the former U.S.S.R. developed their commercial contacts with market economy countries. The Donskoy Ore Dressing Complex and the Aktubinsk Ferroalloy Works (Kazakhstan Republic) developed commercial relations with Japan. Donskoy has exported through the Black Sea port of Poti (Georgia Republic) but developed transportation by train through Siberia to the Eastern port of Nakhodka, a more convenient port from which to ship to Japan. Since 1982 chromite ore and ferrochromium exports from the U.S.S.R. to Japan have increased. Chromite ore from the U.S.S.R. has represented from 2% to 10% of Japanese imports, with no clear trend, while ferrochromium from the former U.S.S.R. has represented from 0% to about 2.5% of Japanese imports with an increasing trend over the time period.

Chromite Ore.—The Donskoy Ore Dressing Complex operated surface and underground chromite mines and an ore beneficiation plant. Proven reserves were estimated to have been about 300 million tons with inferred and estimated reserves at about 1 billion tons. Production at Donskoy was reported to have been about 3.6 million tons per year, with plans to increase that rate to 4.0 million tons per year in 1993. Donskoy surface mines included three working faces: 40 Years of Kazakh SSR, Mirny, and Objedinyonny. A fourth face, Dehgiz Agach, was being planned. The largest operation is the 40 Years of Kazakh SSR, where a 1,270-meter by 1,100-meter by 220-meter volume is mined in 16-meter by 20-meter benches to produce about 1.7-million-ton-per-year run-of-mine ore graded at 47% to 49% Cr₂O₃, with production planned to increase to 2.0 million tons per year. Donskoy underground mines included the Molodyozhnaya and Tsentraljinaya. A third underground operation, Glubokoe, was being planned. Production from the Molodyozhnaya Mine was about 1.5 million tons per year at an average grade

of about 44.8% Cr₂O₃. The beneficiation facilities included two ore dressing plants. One plant produced about 1.3 million tons per year while the other produced about 0.7 million tons per year. The 0.7-million-ton-per-year plant was being renovated to produce about 2.0 million tons per year with a target completion date of 1992. Donskoy was also constructing a briquetting facility targeted for completion in 1992. The briquettes were planned to be used within the country to produce ferrochromium. Chromite ore product from Donskoy ranges in grade from 42% to 57% Cr₂O₃, Cr:Fe from 2.8 to 4.2, in a variety of sizes up to about 300 millimeters. Donskoy has exported through Poti, Republic of Georgia, which is 2,800 meters by rail from the complex. More recently, Donskoy has exported through Nakhodka on the east coast of Russia, which is about 6,000 kilometers from the complex by the trans-Siberian railroad. Donskoy planned to develop an export option through the Ukraine Republic.

Chromium Ferroalloy and Metal.—Aktubinsk Ferroalloy Works, Kazakhstan, operated 14 shaft furnaces, 3 vacuum furnaces, 2 grain refining furnaces, and 2 converter furnaces to produce high-, medium-, and low-carbon ferrochromium, ferrochromium-silicon, and nitrogen-bearing ferrochromium with an annual capacity of about 340,000 tons per year. Chelyabinsk Elektrometallurgical Works, Russia, produced low-carbon ferrochromium and ferrochromium-silicon. Production in 1989 was reported to have been about 210,400 tons of high-carbon ferrochromium, 37,700 tons of foundry-grade ferrochromium, and 135,000 tons of ferrochromium-silicon. Klyuchevsk Ferroalloy Works, Sverdlovsk Region, Russia, produced low-carbon ferrochromium and chromium metal. Serovsk Ferroalloy Works, Sverdlovsk Region, Russia, operated two chromium ferroalloy plants, each consisting of nine electric furnaces that produced high-, medium-, and low-carbon ferrochromium and ferrochromium-silicon. Production in 1989 was reported to have been about

90,000 tons of high-carbon ferrochromium, 34,000 tons of medium-carbon ferrochromium, 121,000 tons of low-carbon ferrochromium, and 12,700 tons of ferrochromium-silicon. Yermakovskiy Ferroalloy Works, Pavlovsk Region, Kazakhstan, produced ferrochromium and ferrochromium-silicon. Zaporozhye Ferroalloy Works, Ukraine, produced ferrochromium.

Chromite Refractories.—Krasnoarmeiskiy Silica Works, Donetsk Region, Russia, produced chromite-periclase refractories with an annual production capacity of about 50,000 tons. Nikitovskiy Dolomite Works, Donetsk Region, Russia, produced unshaped chrome-magnesia refractories.

Vietnam.—International Mineral Research (Australia) reported that Vietnam was seeking foreign investment in its mining industry since it introduced new mining laws in 1988. Chromite production in Vietnam peaked at 36,000 tons in 1968 but has been only 4,000 tons in recent years.

Yugoslavia.—Political changes resulted in armed conflict in Yugoslavia following the separation of Slovenia, Croatia, and Bosnia and Hercegovina from Yugoslavia. Hemijsko-Elektrometallurški Kombinat Jugohrom, which had been a major ferroalloy producer, is in the Macedonia region of Yugoslavia, but did not produce ferrochromium in 1991. Tvornica Karbida i Ferolegura Dalmacija has an annual high-carbon ferrochromium production capacity of about 70,000 tons and is in Dugi Rat, Croatia. Tovarna Dušika Ruše has an annual low-carbon ferrochromium capacity of about 5,500 tons and is in Slovenia. Civil strife interfered with production.

Zimbabwe.—It was reported that 62 chromite mines were operating in Zimbabwe in 1991, most of which were small mining cooperatives. The mining industry reportedly generated about 45% of Zimbabwe's foreign exchange earnings with ferrochromium accounting for the

largest single share in 1988 at about 15%.

The Government of Zimbabwe, Union Carbide (owner of Zimbabwe Mining and Smelting), Anglo American Corp. (owner of Zimbabwe Alloys) and Atlas Copco-Eickhoff (Germany) studied the potential of mechanized mining of chromite from the northern great dyke, a thin seam deposit. Zimbabwe Alloys produced ferrochromium-silicon, with an annual capacity of about 55,000 tons, about one-half of which was used within the plant to produce low-carbon ferrochromium, and low-carbon ferrochromium, with an annual capacity of about 36,000 tons per year. Zimbabwe Mining and Smelting operated six electric arc furnaces, five at 17 megawatts and one at 12.5 megawatts, and one induction furnace at 3.5 megawatts to produce high-carbon ferrochromium with an annual production capacity approaching 200,000 tons and containing chromium in the range of 65.5% to 66%. Zimbabwe Mining and Smelting planned the installation of a second induction melting furnace and the possible addition of a seventh smelting furnace contingent upon development of an efficient mechanized mining method for northern dyke chromite deposits. Zimbabwe Mining and Smelting was installing dust collection equipment. All of the furnaces were to have dust control equipment by 1995. (See tables 26 and 27.)

Current Research

U.S. Bureau of Mines research provides fundamental scientific and technical information essential for advancing mineral science, processing technology, and conserving and developing domestic mineral resources. This research is conducted in support of the Strategic and Critical Materials Stock Piling Act of 1946 as amended, the Defense Production Act of 1950 as amended, the Mining and Minerals Policy Act of 1970, and the National Materials and Minerals Policy, Research and Development Act of 1980. Recent research related to chromium includes the study of chromite recovery from domestic

deposits, the development of analytic techniques to study chromium alloys, and the recovery of chromium from waste.

The U.S. Bureau of Mines studied domestic chromite ore resources from the Pennsylvania-Maryland area. The Bureau conducted magnetometer traverses in the State line district of Pennsylvania and Maryland to determine the geophysical response of the area. While chromite only rarely can be detected directly by magnetic methods, there is a possibility that geophysical signatures in the host rock could provide some guidelines for further exploration. The study did not find this method to be useful nor did it rule out the method for the study of chromite deposits in this area.¹⁷

The U.S. Bureau of Mines studied eutectic formation (formation of a mixture of phases that do not form solid solutions) in white cast irons and the recovery of chromium from superalloy scrap. The Bureau used electron microprobe analysis, X-ray diffraction, and scanning electron and optical microscopy to study the effect of chromium and other elements on the structure and morphology of the eutectic carbides. Differential thermal analysis was used to study the effects of alloying additions on the solidification reactions. Effects observed were explained in terms of the effects of alloying elements on the liquidus surface of the metastable iron-chromium-carbon phase diagram.¹⁸ The Bureau developed a procedure to recover chromium from mixed and contaminated superalloy scrap that uses both pyrometallurgical and hydrometallurgical methods. Chromium and iron were recovered together by precipitation.¹⁹

The U.S. Bureau of Mines analyzed the chromium and other elemental contents of U.S.-produced stainless and heat-resisting steel. The Bureau found that the 1962-83 average chromium fraction of U.S.-produced stainless and heat-resisting steel to have been about 0.17 ± 0.01 . The unit consumption of chromium was found to have declined with the increased use of Type 409, a ferritic stainless grade that is also one of the lowest chromium-containing stainless alloys. Type 409 was adopted for use in

automobile exhaust systems when that industry elected to meet EPA air emission standards through the use of catalytic converters.²⁰

A refractory metals symposium recently reviewed several aspects of chromium. Chromium recovery from mixed contaminated superalloy scrap as a ferroalloy was demonstrated. Treatment included pyrometallurgical and hydrometallurgical processes.²¹ Chromium recovery in the form of sodium chromate from Egyptian chromite ore was studied using a process that first sinters and then roasts the sinter. Chromium recoveries of near 100% dependent on roasting time and temperature and sodium carbonate and calcium oxide additions were achieved.²² The reduction of chromium (VI) to chromium (III) in a liquid fluidized bed electrochemical reactor was studied. The process is a possible alternative to one of several used by electroplaters to meet EPA effluent requirements. The effect of varying anode materials and mixing electrolyte streams were determined.²³

The Department of Agriculture developed a process that separates chromium from solid leather waste. Chromium sulfate is applied to animal hides to stabilize and preserve the hides. Separation of chromium from leather waste contributes both to chromium recovery and the reduction of waste disposal cost.²⁴

The Council for Mineral Technology (MINTEK) of the Republic of South Africa conducts government-sponsored and commercially sponsored and cosponsored research and development on chromite ore and ferrochromium. Recent MINTEK research has included chromite beneficiation, agglomeration, and smelting. MINTEK reported on the development, up to industrial scale, of a transferred plasma-arc smelting process for the production of ferrochromium. MINTEK commercial-scale transferred plasma-arc furnace and furnace control technology was industrially implemented.²⁵

MINTEK reported on the effect of technology and cost on the Republic of South Africa's international

ferrochromium market. The major ferrochromium operating production costs were identified to be about 30% for chromite ore feed, 20% for other material feed (reducing agents, fluxes, electrodes, and fuel), 40% for electrical energy, and 10% for labor and maintenance. Capital costs were found to be process sensitive. Capital cost of the traditional submerged-arc furnace was lowest, followed by plasma-arc then kiln roasting direct reduction. It was found that from 1970 to 1989 ferrochromium annual production capacity in the Republic of South Africa grew from about 0.1 to 1 million tons, an average annual rate of about 15%. In the 1990-91 time period, an additional 0.5 million tons of production capacity was added. It was projected that South African ferrochromium production would increase from an annual rate of about 1 million tons in 1989 to about 2.1 million tons in the year 2000.²⁶

The application of nickel sulfide to a reduction process of Canadian chromites (Bird River, Manitoba) was reported. Nickel was used in the smelting process to produce a high-carbon ferrochromium-nickel product usable as a master alloy for stainless steel production. A major condition for master alloy production is that contaminant levels be acceptable to stainless steel production. Laboratory-scale master alloy was produced, suggesting that a master alloy containing 40% chromium, 19% nickel, 0.04% sulfur, 0.5% carbon, and 0.5% silicon could be produced at commercial scale.²⁷

Private industry researched more economic production and utilization processes. Industry studied the application of hollow cathode technology to the production of ferrochromium from chromite ore fines. Hollow cathode use permits the direct use of fine ore, avoiding the need for agglomeration. Several process and product improvements were achieved.²⁸

Environmental concerns about chromium have resulted in a wide variety of studies to determine the natural background levels, sources of environmental emissions, movement of chromium in the environment, interaction of chromium with plants and animals,

effect of chromium on plants and animals, measurement methods, and recovery technology. A broad review of many environmental factors and the role of chromium, among other metals, in the environment was published.²⁹

OUTLOOK

On average in the United States, about 70% of chromium is consumed by the metallurgical industry, and about 70% of metallurgical industry chromium consumption is for stainless steel production. Stainless steel, by definition, contains at least 11% chromium but may contain up to 36% chromium. Thus, stainless steel production accounts for about one-half of the chromium consumed in the United States. The remainder is consumed in the production of other ferrous and nonferrous alloys, chemicals, and refractories. Some of the chemical and refractory products are consumed in the steel production process.

On average internationally, about 79% of chromium is consumed by the metallurgical industry, 13% by the chemical industry, and 8% by the refractory industry. Of the chromium consumed in the metallurgical industry, about 60% is consumed in stainless steel. Thus, stainless steel production accounts for about one-half of the chromium consumed internationally.³⁰

The outlook for chromium consumption in the United States and internationally is the same as that for stainless steel. Stainless steel is estimated to be the major end use for chromium worldwide. Thus, stainless steel industry performance determines chromium industry demand worldwide. (See table 28.)

The trend to supply chromium in the form of ferrochromium by chromite mining countries is expected to continue. The rate at which new ferrochromium plants come into production is expected to diminish now that all major chromite producers have such facilities. With new, efficient ferrochromium production facilities and excess capacity in chromite-producing countries, both production and capacity are expected to diminish in

traditional ferrochromium-producing countries, except where domestic industries are protected by quotas and tariffs. Further upward integration of the chromium industry is expected as chromite-producing countries expand current capacity or develop new stainless steel production capacity.

Stainless Steel

As pointed out above, chromium demand is driven by stainless steel demand. Stainless steel demand is price sensitive and an important part of stainless steel cost is nickel cost (about 70% of stainless steel requires nickel). One factor that could effect chromium demand is the availability of inexpensive nickel. Nickel availability is adequate to meet current demand and anticipated stainless steel demand until about 1995, at which time new nickel production capacity may be needed to meet demand. Projected cost of new nickel production capacity could be substantially higher than that of currently available material.³¹ After 1995, the increasing cost of nickel may result in increased stainless steel cost, which could result in reduced demand for stainless steel. Thus, just when stainless steel demand for chromium is anticipated to come into equilibrium with ferrochromium production capacity, demand may decline, reducing chromium industry growth after 1995. Several factors could modify this scenario. The role of the previously centrally planned economy countries both in terms of nickel supply and stainless steel demand are ambiguous. The balance between reduction in cost owing to greater production rates may offset some nickel increases. Stainless steel producers could substitute manganese for nickel, thereby reducing the impact of nickel cost increases. Short-term fluctuations in demand could exceed these longer term average projections.

Chromium Chemicals³²

Chromium chemical markets were reviewed. U.S. demand for sodium bichromate was reported to have been

130,200 tons in 1990 and was projected to be 130,800 tons in 1991 and 133,400 tons in 1995. The domestic chromium chemicals market showed -0.7% growth from 1981 through 1990 and was expected to show a positive 1% growth from 1991 through 1995. Reported prices for sodium bichromate crystals was \$0.60 per pound of sodium bichromate dihydrate equivalent content (for pricing purposes, sodium bichromate dihydrate equivalent content of crystals is 100%) and sodium bichromate liquor was \$0.55 per pound of sodium bichromate dihydrate equivalent content (typically the sodium bichromate dihydrate equivalent content of liquor ranges from 69% to 70%). Sodium bichromate was used as follows: chromic acid, 55%; chromium oxide, 10%; leather tanning, 8%; pigments, 7%; wood preservatives, 2%; drilling mud additives, 2%; other uses (including metal finishing, water treatment, textiles, and catalysts), 3%; and export, 13%. Environmental concerns were seen as driving the chromium chemicals markets.

Demand for chromic acid was expected to continue to grow at an annual rate of about 2% to 3% through 1995. Domestic chromic acid producers, American Chrome and Chemicals and Occidental Chemicals, increased their chromic acid production capacity to the current annual rate of 71,000 tons to meet increasing demand. Chromic acid prices were about \$1.10 to \$1.15 per pound in 400-pound drums. Chromic acid was consumed for the production of wood preservatives, metal finishing, and chromium dioxide. Wood preservation currently accounts for about 70% of chromic acid demand and was expected to increase even though chromium chemicals account for about 70% of the U.S. wood treatment market. Environmental restrictions on the use of creosote (in marine pilings) and pentachlorophenol (in utility poles) are expected to result in greater use of chromic acid for wood preservation. The most widely used chromium-containing wood preservative is chromium copper arsenate (CCA). CCA-treated wood is resistant to decay and termite attack, and wood treated with CCA is easier to paint

than wood treated with oil-base formulations. CCA-treated wood thus finds use in roofing, outdoor decks, and house foundations. Metal finishing accounts for about 27% of chromium oxide demand. Metal finishing includes chromium plating, aluminum anodizing, and other metal treatments. No growth was anticipated for metal finishing. The remaining 3% of chromic acid consumption included the production of chromium dioxide, a growth market that included the production of magnetic particles for use in magnetic recording media (audio and video tapes and computer disks).

EPA regulation limiting chromium releases have encouraged recycling of chromium chemicals and the use of substitutes to reduce releases. As a result, demand is expected to be reduced for many end uses.

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TABLE 1
COMPOSITION OF TYPICAL CHROMIUM FERROALLOYS AND CHROMIUM METAL

(Composition, percentage)

Material ¹	Grade	Chromium ²	Carbon ³	Silicon ³	Sulfur ³	Phosphorus ³	Nitrogen ³
Ferrochromium:							
High-carbon	A	52-58	6.0-8.0	6.0	0.040	0.030	0.050
Do.	B	55-64	4.0-6.0	8.0-14.0	.040	.030	.050
Do.	C	62-72	4.0-9.5	3.0	.060	.030	.050
Low-carbon	A	60-67	.025	1.0-8.0	.025	.030	.12
	B	67-75	.025	1.0	.025	.030	.12
	C	67-75	.050	1.0	.025	.030	.12
	D	67-75	.75	1.0	.025	.030	.12
Vacuum low-carbon	E	67-72	.020	2.0	.030	.030	.050
	F	67-72	.010	2.0	.030	.030	.050
	G	63-68	.050	2.0	.030	.030	5.0-6.0
Nitrogen-bearing	—	62-70	.10	1.0	.025	.030	1.0-5.0
Ferrochromium-silicon	A	34-38	.060	38-42	.030	.030	.050
	B	38-42	.050	41-45	.030	.030	.050
Chromium metal	A	99.0	.050	.15	.030	.010	.050
	B	99.4	.050	.10	.010	.010	.020

¹Chemical requirements in addition to those listed here are specified by American Society for Testing Materials (ASTM).

²Minimum, except where range of values indicating minimum and maximum appears.

³Maximum, except where range of values indicating minimum and maximum appears.

Source: 1988 Annual Book of ASTM Standards.

TABLE 2
PRINCIPAL WORLD CHROMITE PRODUCERS, 1991

Country ¹	Company
Albania	Government owned.
Brazil	Bayer AG (Germany) Coitezeiro Mineração S.A. Cia. de Ferro-Ligas de Bahia S.A. Cia. de Mineração Serra de Jacobina S.A. Mineração Vale do Jacurici S.A. Magnesita S.A.
Finland	Outokumpu Oy (Government owned).
India	Ferro Alloys Corp. Ltd. Misrilal Mines Pvt. Ltd. Mysore Mineral Ltd. Orissa Mining Corp. Ltd. (Government owned). Tata Iron and Steel Co.
Philippines	Acoje Mining Co. Inc. Benguet Corp. Philchrome Mining Corp.
South Africa, Republic of	African Mining and Trust Co. Ltd. Zeerust Chrome Mine Ltd. Rustenburg Minerals Development Co. (Pty.) Ltd. Chrome Chemicals SA (Pty.) Ltd. Chromecorp Technology (Pty.) Ltd. Chroombronne (Pty.) Ltd. Lavino South Africa (Pty.) Ltd. Grootboom Chrome Mine. Lebowa Development Corp. Ltd. Dilokong Chrome Mine. National Manganese Mines (Pty.) Ltd. Buffels Chrome Mine. Samancor Ltd. Bathako Mining Ltd. Ruighoek Chrome Mine. Grasvally Chrome Mine. Henry Gould (Pty.) Ltd. Jagdlust Mine. Millsell Chrome Mines (Pty.) Ltd. Montrose Mine. Mooinooi Mine. Waterkloof Chrome Mines (Pty.) Ltd. Winterveld Chrome Mines Ltd. Vereeniging Refractories Ltd. Marico Chrome Corp. (Pty.) Ltd.
Turkey	Elibank (Government owned). Bursa Toros Kromlari AS. Egemetal Madencilik AS. Sitki Kocman Mines. Turk Maadin Sirketi AS. Hayri Ogelman Madencilik AS.
U.S.S.R.	Government owned.
Zimbabwe	Zimbabwe Alloys Ltd. Zimbabwe Mining and Smelting Co. (Pvt.) Ltd.

¹Other chromite-producing countries included Bulgaria, China, Cuba, Greece, Indonesia, Iran, Japan, Madagascar, New Caledonia, Pakistan, Sudan, Thailand, Yugoslavia, and Vietnam.

TABLE 3
PRINCIPAL WORLD FERROCHROMIUM PRODUCERS, 1991

Country ¹	Company
Brazil	Cia. de Ferro-Ligas da Bahia S.A.
China	Government owned.
Finland	Outokumpu Oy (Government owned).
France	Chromeurope S.A.
Germany	Gesellschaft für Elektrometallurgie mbH Elektrowerk Weisweiler GmbH.
Greece	Hellenic Ferroalloys S.A.
India	Ferro Alloys Corp. Ltd. Indian Metals & Ferroalloys Ltd. Indian Charge Chrome Ltd. Industrial Development Corp. Tata Iron and Steel Co. OMC Alloys Ltd. Visvesvaraya Iron & Steel Ltd. (State owned)
Italy	Acciaierie e Ferriere Lombarde Falck SpA. Ferroleghe SpA.
Japan	Japan Metals and Chemicals Co. Ltd. Nippon Denko Co. Ltd. NKK Corp. Pacific Metals Co. Ltd. Showa Denko K.K.
Norway	Elkem Rana.
Philippines	Ferro Chemicals Inc. Ferrochrome Philippines Inc. Integrated Chrome Corp.
South Africa, Republic of	Anglovaal Ltd. Feralloys Ltd. Chromecorp Technology (Pty.) Ltd. (CCT) Johannesburg Consolidated Investment Co. Ltd. Consolidated Metallurgical Industries Inc. (CMI) Purity Ferrochrome (Pty.) Ltd. Samancor Ltd. Bathako Ferrochrome Ltd. Ferrometals Ltd. Middelburg Steel and Alloys Holdings (Pty.) Ltd. (MS&A) Alloys Division Middelburg. Alloys Division Krugersdorp. Tubatse Ferrochrome (Pty.) Ltd.
Sweden	Vargön Alloy AB.
Turkey	Etibank (Government owned).
U.S.S.R.	Government owned.
United States	Elkem Metals Co. Macalloy Corp. SKW Alloys Inc.
Yugoslavia	Tvornica Karbida i Ferolegura Dalmacija. Tovarna Dušika Ruše.
Zimbabwe	Zimbabwe Alloys Ltd. Zimbabwe Mining and Smelting Co. (Pvt.) Ltd.

¹Other ferrochromium-producing countries included Albania, Chile, Czechoslovakia, Poland, Mexico, Romania, Spain, and Taiwan.

TABLE 4
TIME-VALUE¹ RELATIONSHIPS FOR CHROMITE ORE

(Average annual value, dollars per metric ton of contained chromium)

Year	Not more than 40% chromic oxide		More than 40% but less than 46% chromic oxide		46% or more chromic oxide		Total, all grades	
	Actual	Constant dollar	Actual	Constant dollar	Actual	Constant dollar	Actual	Constant dollar
1963	86	315	40	146	63	232	54	197
1964	84	302	44	157	59	212	57	205
1965	88	309	48	169	59	208	59	209
1966	82	279	45	154	62	211	58	198
1967	87	289	48	159	66	218	62	205
1968	81	256	45	142	60	191	59	185
1969	75	226	51	153	66	198	64	192
1970	85	243	53	151	90	256	79	226
1971	98	265	58	157	98	264	87	235
1972	99	254	62	159	94	242	89	230
1973	104	252	55	132	93	225	82	199
1974	109	244	67	150	104	231	96	213
1975	178	362	101	206	209	425	175	355
1976	222	425	146	279	262	501	212	405
1977	235	421	166	296	254	454	206	368
1978	230	381	177	293	185	307	200	331
1979	240	367	187	285	232	354	215	329
1980	288	402	195	272	189	263	222	310
1981	266	337	192	244	184	234	219	277
1982	293	350	201	239	213	254	229	273
1983	359	412	172	198	166	190	194	223
1984	403	443	141	154	156	172	186	204
1985	261	277	160	170	160	169	184	195
1986	218	225	145	149	146	151	163	169
1987	185	185	160	160	155	155	168	168
1988	241	232	269	259	187	180	229	220
1989	292	269	290	267	247	228	271	250
1990	313	277	228	202	237	210	242	214
1991	562	² 480	209	¹ 179	263	² 225	232	¹ 198

¹Preliminary.

²Customs value per ton of chromium contained in imported material.

NOTE.—Constant dollar value is actual value multiplied by gross domestic product (GDP) ratio. GDP ratio is annual GDP index divided by 1987 GDP index. GDP ratio calculated as the ratio of GDP indices reported in Economic Report of the President, U.S. Government, Feb. 1992, available from Superintendent of Documents, U.S. Government Printing Office.

TABLE 5
TIME-VALUE¹ RELATIONSHIPS FOR FERROCHROMIUM AND CHROMIUM METAL

(Average annual value)

Year	Ferrochromium (dollars per metric ton of contained chromium)						Chromium metal (dollars per metric ton gross weight)	
	Low-carbon ²		High-carbon ³		Total, all grades		Actual	Constant dollar
	Actual	Constant dollar	Actual	Constant dollar	Actual	Constant dollar		
1963	397	1,461	290	1,067	376	1,383	1,677	6,165
1964	380	1,371	304	1,098	360	1,300	1,670	6,029
1965	408	1,437	268	942	395	1,390	1,661	5,849
1966	410	1,394	232	789	367	1,249	NA	NA
1967	417	1,375	264	870	394	1,301	NA	NA
1968	399	1,260	261	824	382	1,204	1,656	5,224
1969	426	1,279	236	710	370	1,112	1,800	5,405
1970	453	1,290	272	775	401	1,142	NA	NA
1971	585	1,582	342	925	464	1,254	2,003	5,414
1972	556	1,433	282	727	422	1,089	2,206	5,686
1973	617	1,493	289	700	392	948	2,491	6,031
1974	797	1,776	512	1,141	600	1,335	3,030	6,748
1975	1,534	3,119	942	1,914	1,061	2,157	4,486	9,118
1976	1,406	2,688	719	1,376	916	1,751	4,350	8,317
1977	1,385	2,478	702	1,255	826	1,477	4,938	8,834
1978	1,405	2,329	640	1,061	686	1,138	NA	NA
1979	1,737	2,652	853	1,303	945	1,443	NA	NA
1980	1,826	2,546	890	1,241	972	1,355	7,682	10,714
1981	1,609	2,040	870	1,102	952	1,206	7,662	9,711
1982	1,551	1,851	887	1,058	1,008	1,202	6,018	7,181
1983	1,437	1,648	683	783	737	845	4,491	5,150
1984	1,496	1,644	782	860	833	916	5,674	6,235
1985	1,571	1,664	847	897	914	968	5,468	5,792
1986	1,409	1,454	779	804	851	878	5,320	5,490
1987	[†] 1,543	1,543	783	783	893	893	[†] 6,097	6,097
1988	1,988	1,914	1,317	1,268	1,403	1,351	7,231	6,960
1989	[†] 1,909	1,761	1,524	1,406	1,609	1,484	6,598	6,087
1990	1,619	1,434	[†] 883	782	1,017	901	6,459	5,721
1991	1,991	[†] 1,702	874	[†] 747	997	[†] 852	7,584	[†] 6,482

[†]Preliminary. [‡]Revised. NA Not available.

¹Customs value per ton of chromium contained in imported material.

²Carbon not more than 4%.

³More than 4% carbon.

NOTE.—Constant dollar value is actual value multiplied by gross domestic product (GDP) ratio. GDP ratio is annual GDP index divided by 1987 GDP index. GDP ratio calculated as the ratio of GDP indices reported in Economic Report of the President, U.S. Government, Feb. 1992, available from Superintendent of Documents, U.S. Government Printing Office.

**TABLE 6
AVAILABILITY OF CHROMITE AND CHROMIUM FERROALLOYS
FROM 10 MARKET ECONOMY COUNTRIES**

Chromium materials	Quantity available (million metric tons, gross weight)	Cost ¹ (dollars per metric ton)	
		Weighted average	Range
Chromite:			
Chemical grade	64.3	53	\$35- 174
Foundry sand grade	16.4	49	39- 83
Metallurgical grade:			
Primary product	145.4	101	42- 705
Secondary product	35.6	54	33- 117
Subtotal (metallurgical)	181.0	92	33- 705
Refractory grade	26.8	87	54- 180
Total (chromite)	288.5		
Chromium ferroalloys:			
Ferrochromium:			
High-carbon ferrochromium	74.3	473	417-1,286
Low-carbon ferrochromium	3.9	937	635-1,309
Ferrochromium-silicon	2.0	737	578- 814
Total	80.2		

¹Cost of production for zero percent discounted cash flow rate of return in Jan. 1989 dollars per metric ton, gross weight, of product f.o.b. ship at port of export.

**TABLE 7
SALIENT CHROMIUM STATISTICS**

(Thousand metric tons, gross weight)

	1987	1988	1989	1990	1991
CHROMITE					
United States:					
Exports	1	4	40	6	9
Reexports	5	1	2	4	—
Imports for consumption	490	615	525	306	212
Consumption	506	551	561	405	375
Stocks, December 31: Consumer	332	390	392	355	321
World production	11,919	12,890	14,179	12,848	13,237
CHROMIUM FERROALLOYS¹					
United States:					
Net production ²	107	120	147	109	68
Exports	5	8	9	9	11
Reexports	2	2	2	2	2
Imports for consumption	303	431	351	420	407
Consumption	396	413	354	382	361
Stocks, December 31: Consumer	23	30	19	17	18
World production	3,307	3,715	4,067	3,522	3,465

¹Estimated. ²Preliminary. ³Revised.

¹High-, medium-, and low-carbon ferrochromium plus ferrochromium-silicon.

²Includes chromium metal, exothermic chromium additives, and other miscellaneous alloys.

TABLE 8
HISTORICAL AND PROJECTED PERFORMANCE OF THE NATIONAL DEFENSE STOCKPILE CHROMITE ORE TO FERROCHROMIUM CONVERSION PROGRAM

Contract year	Ore converted (metric tons)	High-carbon ferrochromium produced (metric tons)		Cost (millions)
		Gross	Content	
HISTORICAL PERFORMANCE				
1984	113,968	45,590	30,180	\$22.3
1985	124,298	44,872	29,630	22.5
1986	85,301	31,944	20,898	17.6
1987	125,739	52,414	40,058	28.8
1988	111,105	41,511	26,727	26.7
1989	120,651	46,940	30,392	31.5
1990	113,453	42,881	28,082	30.9
1991	111,511	42,577	28,178	31.0
PROJECTED PERFORMANCE*				
1992	103,977	46,707	NA	32.7
1993	112,238	51,424	NA	34.2

*Estimated. NA Not available.

Source: Defense Logistics Agency.

TABLE 9
HISTORICAL AND PROJECTED PERFORMANCE OF THE NATIONAL DEFENSE STOCKPILE LOW-CARBON FERROCHROMIUM TO CHROMIUM METAL CONVERSION PROGRAM

Time period	Low-carbon ferrochromium ¹ (metric tons)	Chromium metal (metric tons)	Cost (millions)
HISTORICAL PERFORMANCE			
October 1989 - September 1990	2,129	¹ 1,048	\$7.3
October 1990 - September 1991	1,090	780	7.0
PROJECTED PERFORMANCE*			
October 1991 - September 1992	NA	1,020	10.1

*Estimated. ¹Revised. NA Not available.

¹Nonspecification grade.

Source: Defense Logistics Agency.

TABLE 10
U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND INVENTORIES
FOR CHROMIUM IN 1991

(Thousand metric tons, gross weight)

Material	Physical inventory			Total ¹
	Stockpile goals	Stockpile grade	Nonstock-pile-grade	
Chromite, metallurgical	2,903	1,174	197	1,371
Chromite, chemical	612	220	—	220
Chromite, refractory	630	355	—	355
High-carbon ferrochromium	168	671	1	671
Low-carbon ferrochromium	68	272	15	288
Ferrochromium-silicon	82	52	1	53
Chromium metal	18	4	—	4

¹Data may not add to total shown because of independent rounding.

Source: Defense Logistics Agency.

TABLE 11
PRINCIPAL U.S. PRODUCERS OF CHROMIUM PRODUCTS IN 1991, BY
INDUSTRY

Industry and company	Plant
Metallurgical:	
Elkem AS, Elkem Metals Co.	Marietta, OH, and Alloy, WV.
Macalloy Corp.	Charleston, SC.
Satra Concentrates Inc.	Steubenville, OH.
SKW Alloys Inc.	Calvert City, KY, and Niagara Falls, NY.
Refractory:	
General Refractories Co.	Lehi, UT.
Harbison-Walker Refractories, a division of Dresser Industries Inc.	Hammond, IN.
National Refractories & Mining Corp.	Moss Landing, CA, and Columbiana, OH.
North American Refractories Co. Ltd.	Womelsdorf, PA.
Chemical:	
American Chrome & Chemicals Inc.	Corpus Christi, TX.
Occidental Chemicals Corp.	Castle Hayne, NC.

TABLE 12
PRODUCTION, SHIPMENTS, AND STOCKS
OF CHROMIUM FERROALLOYS AND METAL, AND OTHER
CHROMIUM MATERIALS
IN THE UNITED STATES

(Metric tons)

Year	Net production		Net shipments	Producer stocks, December 31
	Gross weight	Chromium content		
1987	106,716	68,614	114,734	5,114
1988	119,645	73,282	115,499	8,831
1989	146,844	90,073	135,361	20,475
1990	108,932	67,701	91,735	14,935
1991	68,327	43,061	75,286	11,832

TABLE 13
CONSUMPTION OF CHROMITE AND TENOR OF ORE USED BY
PRIMARY CONSUMER GROUPS IN THE UNITED STATES

Year	Chemical and metallurgical industry		Refractory industry		Total ¹	
	Gross weight (metric tons)	Average Cr ₂ O ₃ (percentage)	Gross weight (metric tons)	Average Cr ₂ O ₃ (percentage)	Gross weight (metric tons)	Average Cr ₂ O ₃ (percentage)
1987	458,536	41.0	47,586	39.9	506,122	40.9
1988	494,713	42.8	55,923	38.9	550,636	42.4
1989	516,931	42.8	43,780	39.5	560,711	42.6
1990 ^r	361,176	43.8	44,237	39.8	405,413	43.3
1991	339,068	45.4	36,016	40.1	375,084	44.9

^rRevised.

¹Data may not add to totals shown because of independent rounding.

TABLE 14
U.S. CONSUMPTION OF CHROMIUM FERROALLOYS AND METAL,
BY END USE

(Metric tons, gross weight)

End use	Ferrochromium		Ferrochromium-silicon	Other	Total ³
	Low-carbon ¹	High-carbon ²			
1990:					
Steel:					
Carbon	3,192	4,079	276	¹ 184	⁷ 7,547
Stainless and heat-resisting	⁷ 7,096	² 287,651	7,929	151	³ 302,827
Full-alloy	4,171	29,326	1,325	¹ 10	³ 34,822
High-strength, low-alloy and electric	1,977	2,905	⁸ 8,017	² 25	¹ 12,923
Tool	903	2,797	W	—	3,700
Cast irons	³ 3,572	⁵ 5,604	26	6	⁹ 9,208
Superalloys	³ 3,816	4,443	—	³ 3,940	¹ 12,199
Welding materials ⁴	⁴ 458	W	—	¹ 146	¹ 1,413
Other alloys ⁵	1,137	385	—	¹ 1,752	³ 3,273
Miscellaneous and unspecified	² 293	¹ 131	⁸ 86	³ 353	⁸ 863
Total ^{3 6}	² 26,614	³ 338,129	17,659	⁷ 76,567	³ 388,969
Chromium content	¹ 17,912	¹ 196,249	⁶ 6,347	⁵ 5,564	² 226,071
Stocks, December 31, 1990	³ 3,276	¹ 12,292	455	⁸ 938	¹ 17,598
1991:					
Steel:					
Carbon	3,751	6,478	249	195	10,673
Stainless and heat-resisting	8,283	278,108	7,010	136	293,536
Full-alloy	4,163	20,447	1,228	38	25,877
High-strength, low-alloy and electric	1,815	2,480	6,612	—	10,908
Tool	334	2,922	W	5	3,261
Cast irons	W	4,433	16	8	4,458
Superalloys	3,155	3,377	—	3,741	10,273
Welding materials ⁴	339	627	2	161	1,129
Other alloys ⁵	1,226	290	—	1,386	2,902
Miscellaneous and unspecified	3,572	256	58	319	4,205
Total ^{3 6}	26,638	319,418	15,175	⁹ 5,989	367,220
Chromium content	17,967	183,643	5,612	5,225	212,447
Stocks, December 31, 1991	2,440	15,344	365	¹⁰ 623	18,772

⁶Revised. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

¹Low-carbon ferrochromium contains less than 3% carbon.

²High-carbon ferrochromium contains 3% or more carbon.

³Data may not add to totals shown because of independent rounding.

⁴Includes structural and hard-facing welding material.

⁵Includes cutting materials and magnetic, aluminum, copper, nickel, and other alloys.

⁶Includes estimates.

⁷Includes 4,929 tons of chromium metal.

⁸Includes 723 tons of chromium metal.

⁹Includes 4,548 tons of chromium metal.

¹⁰Includes 433 tons of chromium metal.

TABLE 15
U.S. CONSUMER STOCKS OF CHROMITE, CHROMIUM
FERROALLOYS, AND METAL, DECEMBER 31

(Metric tons, gross weight)

Industry	1987	1988	1989	1990	1991
Chromite:					
Chemical and metallurgical	308,870	366,268	368,482	333,224	310,111
Refractory	23,144	23,353	23,791	21,437	11,114
Total	332,014	389,621	392,273	354,661	321,225
Chromium ferroalloy and metal:					
Low-carbon ferrochromium	3,169	5,683	4,397	3,276	2,440
High-carbon ferrochromium	18,023	23,135	14,141	12,929	15,344
Ferrochromium-silicon	505	647	425	455	365
Other ¹	826	960	523	938	623
Total²	22,524	30,425	19,486	17,598	18,772

¹Revised.

¹Includes chromium briquets, chromium metal, exothermic chromium additives, and other miscellaneous chromium alloys.

²Data may not add to totals shown because of independent rounding.

TABLE 16
PRICE QUOTATIONS FOR CHROMIUM MATERIALS AT BEGINNING
AND END OF 1991

Material	January		December	
	Dollars per metric ton of product			
Chromite ore:				
South Africa, Republic of	50-	55	42-	50
Turkey	120-	135	120-	130
Cents per pound of chromium				
High-carbon ferrochromium:				
Domestic: 50% to 55% chromium	54.5		54.5	
Imported:				
50% to 55% chromium	46-	47.5	48.5 -	49.0
60% to 65% chromium	42.25	45.5	46.75-	47.5
Low-carbon:				
Domestic:				
0.05% carbon	95		95	
0.015% carbon (Simplex)	166		166	
Imported:				
0.05% carbon	100-	105	85-	86.5
0.10% carbon	NA		85-	87
Cents per pound of product				
Chromium metal (domestic):				
Electrolytic	370.0		370.0	
Elchrome	422.5		450.0	

¹Revised. NA Not available.

Source: Metals Week.

TABLE 17
U.S. EXPORTS AND REEXPORTS OF CHROMITE ORE AND
CONCENTRATES

Year	Exports		Reexports	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1987	1,145	\$707	4,837	\$352
1988	3,931	1,430	1,032	320
1989	40,445	5,014	2,375	351
1990	6,321	1,488	4,052	513
1991	8,759	2,041	—	—

Source: Bureau of the Census.

TABLE 18
U.S. EXPORTS OF CHROMIUM MATERIALS, BY TYPE

Type	1989	1990	1991		Principal destinations, 1991
	Gross weight (metric tons)	Gross weight (metric tons)	Gross weight (metric tons)	Value (thousands)	
Chromite ore and concentrate	40,445	6,321	8,759	\$2,041	Canada (82%); Mexico (12%).
Metal and alloys:					
Chromium metal ¹	196	338	424	4,691	Japan (36%); Canada (26%); Netherlands (14%); United Kingdom (13%)
Chromium ferroalloys:					
High-carbon ferrochromium ²	³ 9,464	⁵ 5,795	⁶ 7,820	7,166	Mexico (55%); Canada (39%); Egypt (3%).
Low-carbon ferrochromium ⁷	—	⁸ 2,521	⁹ 2,084	3,602	Canada (55%); Mexico (27%); France (9%).
Ferrochromium-silicon	—	¹⁰ 802	¹¹ 745	939	Canada (95%); Mexico (3%).
Chemicals:					
Chromium oxides:					
Chromium trioxide	3,929	4,082	3,967	7,556	Canada (40%); Japan (15%); Republic of Korea (7%); Taiwan (7%); Australia (6%); Italy (4%).
Other	448	1,226	1,500	7,540	Canada (27%); Japan (27%); Mexico (9%); Philippines (8%); Colombia (5%); Hong Kong (4%).
Chromium sulfates	1	44	48	224	Mexico (96%); Canada (4%).
Salts of oxometallic or peroxometallic acids:					
Zinc and lead chromate	152	209	627	1,680	Canada (70%) Mexico (13%); Belgium (12%).
Sodium dichromate	18,556	16,663	16,860	12,767	Thailand (19%); Colombia (13%); Italy (13%); China (11%); Mexico (11%); Spain (10%); Republic of Korea (5%); Taiwan (5%).
Potassium dichromate	46	48	42	80	Canada (65%); Mexico (23%); Bahamas (8%).
Other chromates, dichromates, and peroxochromates	171	228	193	667	United Kingdom (45%); Canada (37%); Mexico (12%).
Pigments and preparations	2,264	2,643	1,969	7,423	Canada (19%); Germany (14%); Philippines (13%); Singapore (10%); Australia (7%); Thailand (7%); Hong Kong (5%).

¹Articles thereof and waste and scrap.

²More than 4% carbon.

³Includes high-, medium-, and low-carbon ferrochromium and ferrochromium-silicon.

⁴Contained 5,647 tons of chromium.

⁵Contained 3,477 tons of chromium.

⁶Contained 4,617 tons of chromium.

⁷Not more than 4% carbon.

⁸Contained 1,517 tons of chromium.

⁹Contained 1,263 tons of chromium.

¹⁰Contained 333 tons of chromium.

¹¹Contained 261 tons of chromium.

Source: Bureau of the Census.

TABLE 19
U.S. IMPORTS FOR CONSUMPTION OF CHROMITE, BY COUNTRY

Country	Not more than 40% Cr ₂ O ₃			More than 40% but less than 46% Cr ₂ O ₃			46% or more Cr ₂ O ₃			Total ¹		
	Gross weight (metric tons)	Cr ₂ O ₃ content (metric tons)	Value (thousands)	Gross weight (metric tons)	Cr ₂ O ₃ content (metric tons)	Value (thousands)	Gross weight (metric tons)	Cr ₂ O ₃ content (metric tons)	Value (thousands)	Gross weight (metric tons)	Cr ₂ O ₃ content (metric tons)	Value (thousands)
1990:												
Canada	54	15	\$5	—	—	—	12	9	\$5	66	24	\$10
Indonesia	—	—	—	20	*8	\$4	—	—	—	20	*8	4
New Caledonia	—	—	—	—	—	—	2,200	1,224	413	2,200	1,224	413
Pakistan	—	—	—	—	—	—	40	24	8	40	24	8
Philippines	13,133	4,716	1,533	—	—	—	522	269	37	13,655	4,985	*1,571
South Africa, Republic of	10,806	1,859	615	129,617	59,025	9,216	120,103	55,885	8,545	260,526	116,769	*18,375
Turkey	25,500	9,150	1,214	—	—	—	3,500	1,610	555	29,000	10,760	1,769
Total ¹	<u>49,493</u>	<u>15,740</u>	<u>3,367</u>	<u>129,636</u>	<u>59,033</u>	<u>9,219</u>	<u>126,377</u>	<u>59,021</u>	<u>9,563</u>	<u>*305,506</u>	<u>133,794</u>	<u>22,150</u>
1991:												
Canada	3,219	1,097	612	—	—	—	36	29	15	3,255	1,126	627
Philippines	5,363	1,771	608	—	—	—	2	1	5	5,365	1,772	613
South Africa, Republic of	—	—	—	139,035	62,976	8,741	33,984	15,988	2,862	173,019	78,964	11,603
Turkey	2,500	795	188	28,000	11,643	1,932	—	—	—	30,500	12,438	2,120
Total ¹	<u>11,082</u>	<u>3,663</u>	<u>1,408</u>	<u>167,035</u>	<u>74,619</u>	<u>10,674</u>	<u>34,022</u>	<u>16,018</u>	<u>2,881</u>	<u>212,139</u>	<u>94,300</u>	<u>14,963</u>

*Estimated. †Revised.

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 20
U.S. IMPORTS FOR CONSUMPTION OF FERROCHROMIUM, BY COUNTRY

Country	Low-carbon (not more than 3% carbon)			Medium-carbon (more than 3% but not more than 4% carbon)			High-carbon (more than 4% carbon)			Total ¹ (all grades)		
	Gross weight (metric tons)	Chromium content (metric tons)	Value (thousands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thousands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thousands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thousands)
1990:												
Albania	—	—	—	—	—	—	1,505	961	\$689	1,505	961	\$689
Australia	—	—	—	—	—	—	294	179	84	294	179	84
Brazil	300	177	\$321	—	—	—	1,250	659	523	1,550	836	844
Canada	1	(?)	2	—	—	—	44	23	23	45	23	25
China	350	225	401	—	—	—	1,270	797	766	1,620	1,022	1,167
Finland	—	—	—	—	—	—	23,849	12,530	12,067	23,849	12,530	12,067
France	90	67	149	—	—	—	884	596	591	974	664	740
Germany, Federal Republic of	11,997	8,498	22,195	—	—	—	47	29	92	12,044	8,527	22,287
Greece	—	—	—	—	—	—	240	157	224	240	157	224
Italy	955	686	1,864	—	—	—	—	—	—	955	686	1,864
Japan	364	251	865	193	131	\$333	387	263	720	944	645	1,919
Mexico	—	—	—	—	—	—	11	6	6	11	6	6
Norway	—	—	—	—	—	—	21,490	13,067	10,865	21,490	13,067	10,865
Philippines	2,554	1,660	1,379	—	—	—	11,793	6,781	4,826	14,347	8,441	6,205
South Africa, Republic of	9,599	5,790	9,703	19,702	10,251	9,095	143,067	74,491	63,033	172,368	90,532	81,831
Spain	—	—	—	—	—	—	1,531	1,008	961	1,531	1,008	961
Sweden	181	135	586	—	—	—	11,821	6,713	5,621	12,001	6,848	6,207
Turkey	9,670	6,716	11,424	—	—	—	35,650	22,353	19,871	45,320	29,070	31,295
United Kingdom	238	159	359	(?)	(?)	(?)	320	139	201	558	299	561
Yugoslavia	—	—	—	—	—	—	48,904	30,975	25,885	48,904	30,975	25,885
Zimbabwe	9,761	6,118	9,050	5,057	3,315	3,801	40,525	26,448	27,863	55,343	35,881	40,715
Total ¹	46,059	30,485	58,299	24,952	13,696	13,230	344,882	198,175	174,911	415,893	242,356	246,439

See footnotes at end of table.

TABLE 20—Continued
U.S. IMPORTS FOR CONSUMPTION OF FERROCHROMIUM, BY COUNTRY

Country	Low-carbon (not more than 3% carbon)			Medium-carbon (more than 3% carbon but not more than 4% carbon)			High-carbon (more than 4% carbon)			Total ¹ (all grades)		
	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou- sands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou- sands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou- sands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou- sands)
1991:												
Brazil	—	—	—	—	—	—	3,950	2,043	\$1,786	3,950	2,043	\$1,786
Canada	—	—	—	—	—	—	28	17	26	28	17	26
China	322	216	\$415	—	—	—	9,447	5,544	4,932	9,769	5,760	5,347
Czecho- slovakia	37	26	46	—	—	—	—	—	—	37	26	46
Finland	—	—	—	—	—	—	30,397	15,873	14,112	30,397	15,873	14,112
France	—	—	—	—	—	—	803	528	547	803	528	547
Germany	10,494	7,454	19,516	—	—	—	173	72	48	10,666	7,526	19,564
Greece	—	—	—	—	—	—	1,250	759	680	1,250	759	680
Italy	176	126	313	—	—	—	82	60	165	258	186	478
Japan	320	229	890	50	34	\$92	996	649	1,488	1,365	912	2,471
Mexico	—	—	—	—	—	—	31	20	22	31	20	22
Norway	—	—	—	—	—	—	16,892	10,420	9,000	16,892	10,420	9,000
South Africa, Republic of	9,797	5,793	9,428	—	—	—	157,464	82,386	72,146	167,261	88,180	81,575
Spain	—	—	—	—	—	—	794	531	556	791	531	556
Sweden	17	13	51	—	—	—	6,754	4,084	3,479	6,772	4,097	3,530
Turkey	9,410	6,438	12,163	—	—	—	49,569	30,323	23,494	58,979	36,762	35,657
U.S.S.R.	59	40	79	—	—	—	1,185	790	477	1,243	830	557
United Kingdom	585	423	1,262	36	24	21	67	46	96	688	493	1,378
Yugoslavia	—	—	—	—	—	—	53,075	33,617	29,119	53,075	33,617	29,119
Zimbabwe	7,237	4,814	6,760	—	—	—	29,041	19,007	18,447	36,278	23,822	25,208
Total ¹	38,453	25,572	50,924	86	58	113	361,998	206,771	180,622	400,536	232,401	231,659

¹Revised.

²Less than 1/2 unit.

³Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 21
U.S. IMPORTS FOR CONSUMPTION OF CHROMIUM MATERIALS, BY TYPE

Type	1989	1990	1991		Principal sources, 1991
	Gross weight (metric tons)	Gross weight (metric tons)	Gross weight (metric tons)	Value (thousands)	
METALS AND ALLOYS					
Chromium metal:					
Waste and scrap	50	85	18	\$104	China (92%); Brazil (8%).
Other than waste and scrap	4,152	6,579	5,747	43,617	United Kingdom (32%); France (24%); China (22%); Japan (19%).
Ferrochromium-silicon	16,803	23,801	35,301	3,517	Zimbabwe (100%).
CHEMICALS					
Chromium oxides and hydroxides:					
Chromium trioxide	661	1,677	1,196	2,285	Italy (57%); Netherlands (18%); Japan (10%); Federal Republic of Germany (10%).
Other	3,880	3,512	3,976	1,141	Federal Republic of Germany (44%); Japan (25%); China (16%); Italy (9%).
Sulfates of chromium	313	192	186	108	Turkey (83%); Mexico (10%); United Kingdom (6%).
Salts of oxometallic or peroxometallic acids:					
Chromates of lead and zinc	607	425	334	698	Poland (48%); Norway (19%); Federal Republic of Germany (13%); France (13%).
Sodium dichromate	5,489	1,661	4,895	2,483	United Kingdom (79%); Mexico (8%); Republic of South Africa (5%).
Potassium dichromate	827	680	464	977	Federal Republic of Germany (35%); U.S.S.R. (32%); United Kingdom (31%).
Other chromates and dichromates; peroxochromates	1,010	1,860	859	2,424	United Kingdom (73%); France (21%).
Chromium carbide	108	123	77	759	United Kingdom (40%); Japan (34%); Federal Republic of Germany (25%).
PIGMENTS AND PREPARATIONS BASED ON CHROMIUM					
Chrome yellow	3,688	3,643	3,468	7,422	Canada (78%); Hungary (11%); Mexico (6%).
Molybdenum orange	1,046	916	812	2,399	Canada (99%).
Zinc yellow	542	436	218	435	Norway (58%); Poland (29%); Mexico (12%).
Other	687	657	441	3,197	Federal Republic of Germany (51%); Japan (17%); Canada (14%); Netherlands (13%); United Kingdom (5%).

¹Contained 2,756 tons of chromium.

²Contained 1,459 tons of chromium.

³Contained 2,046 tons of chromium.

Source: Bureau of the Census.

TABLE 22
U.S. IMPORT DUTIES FOR CHROMIUM-CONTAINING MATERIALS IN 1991

Item	Harmonized Tariff Schedule No.	Most favored nation (MFN)	Non-MFN	Special	
				CA ¹	A, E, IL ²
Chromite ores and concentrates therefrom:					
Not more than 40% Cr ₂ O ₃	2610.00.0020	Free.	Free	NA	NA.
More than 40% and less than 46% Cr ₂ O ₃	2610.00.0040	do.	do.	do.	Do.
Not less than 46% Cr ₂ O ₃	2610.00.0060	do.	do.	do.	Do.
Chromium oxides and hydroxides:					
Chromium trioxide	2819.10.0000	3.7% ad valorem	25% ad valorem	1.4% ad valorem	Free.
Other	2819.90.0000	do.	do.	do.	Do.
Sulfates; alums; peroxosulfates (persulfates):					
Other sulfates: of chromium	2833.23.0000	do.	do.	do.	Do.
Salts of oxometallic or peroxometallic acids:					
Chromates of zinc and of lead	2841.20.0000	do.	do.	do.	Do.
Sodium dichromate	2841.30.0000	2.4% ad valorem	8.5% ad valorem	0.9% ad valorem	Do.
Potassium dichromate	2841.40.0000	1.5% ad valorem	3.5% ad valorem	0.6% ad valorem	Do.
Other chromates and dichromates; peroxochromates	2841.50.0000	3.1% ad valorem	25% ad valorem	1.2% ad valorem	Do.
Carbides, whether or not chemically defined:					
Other: of chromium	2849.90.2000	4.2% ad valorem	do.	1.6% ad valorem	Do.
Pigments and preparations based on chromium:					
Chrome yellow	3206.20.0010	3.7% ad valorem	do.	1.4% ad valorem	Do.
Molybdenum orange	3206.20.0020	do.	do.	do.	Do.
Zinc yellow	3206.20.0030	do.	do.	do.	Do.
Other	3206.20.0050	do.	do.	do.	Do.
Metal and alloys: Ferroalloys:					
Ferrochromium:					
More than 4% carbon	7202.41.0000	1.9% ad valorem	7.5% ad valorem	Free	(³)
More than 3% and not more than 4% carbon	7202.49.1000	do.	do.	do.	Do.
Other (i.e., not more than 3% carbon)	7202.49.5000	3.1% ad valorem	30% ad valorem	do.	Do.
Ferrosilicon chromium	7202.50.0000	10% ad valorem	25% ad valorem	do.	Do.
Other base metals; cermets; articles thereof:					
Chromium:					
Waste and scrap	8112.20.3000	Free	Free	NA	NA.
Other	8112.20.6000	3.7% ad valorem	30% ad valorem	1.4% ad valorem	Free.

NA Not available.

¹United States-Canada Free-Trade Agreement.

²A Generalized System of Preferences, E Caribbean Basin Economic Recovery Act, IL United States-Israel Free-Trade Area Implementation Act of 1985.

³A not applicable. E and IL free.

Source: U.S. International Trade Commission. Harmonized Tariff Schedule of the United States (1991). USITC Publication 2333.

TABLE 23
**WORLD CHROMIUM RESOURCES¹ AND ANNUAL PRODUCTION CAPACITY OF CHROMITE ORE,
 FERROCHROMIUM, CHROMIUM METAL, AND CHROMIUM CHEMICALS IN 1991**

(Thousand metric tons, contained chromium)

	Resources ²			Annual production capacity			
	Reserves	Reserve base ³	Identified resources	Ore	Ferro-chromium	Metal	Chemicals
Albania	1,900	1,900	6,300	218	41	—	—
Argentina	—	—	—	—	—	—	7
Australia	—	500	500	—	—	—	—
Brazil	2,300	4,900	4,900	108	89	(*)	7
Canada	—	1,100	1,100	—	—	—	—
Chile	—	—	—	—	1	—	—
China	NA	NA	NA	13	72	2	NA
Cuba	700	700	2,000	14	—	—	—
Czechoslovakia	—	—	—	—	13	—	—
Egypt	NA	NA	NA	1	—	—	—
Finland	8,900	8,900	8,900	211	105	—	—
France	—	—	—	—	24	2	—
Germany	—	—	—	—	42	1	35
Greece	400	400	800	21	19	—	—
Greenland	—	—	26,000	—	—	—	—
Hungary	—	—	—	—	—	—	2
India	18,100	23,800	23,800	241	167	(*)	5
Indonesia	200	200	200	20	—	—	—
Iran	700	700	17,700	15	—	—	—
Italy	—	—	—	—	64	—	—
Japan	(*)	100	100	3	218	5	23
Korea	—	—	—	—	—	—	4
Madagascar	2,100	2,100	2,100	45	—	—	—
Mexico	—	—	—	—	4	—	—
New Caledonia	—	NA	NA	(*)	—	—	—
Norway	—	—	—	—	88	—	—
Oman	NA	NA	NA	1	—	—	—
Pakistan	NA	NA	NA	2	—	—	1
Papua New Guinea	—	—	2,900	—	—	—	—
Philippines	2,300	2,300	2,300	60	49	—	—
Poland	—	—	—	—	35	—	5
Romania	—	—	—	—	24	—	4
South Africa, Republic of	295,200	1,704,400	2,973,700	1,505	791	—	5
Spain	—	—	—	—	9	—	6
Sudan	500	500	500	2	—	—	—
Sweden	—	—	—	—	100	—	—
Taiwan	—	—	—	—	9	—	—
Thailand	NA	NA	NA	(*)	—	—	—
Turkey	2,500	6,000	6,800	440	70	—	8
U.S.S.R.	39,600	39,600	40,600	1,100	223	6	52
United Kingdom	—	—	—	—	1	5	24
United States	—	3,100	35,000	—	83	4	58
Vietnam	NA	NA	NA	1	—	—	—

See footnotes at end of table.

TABLE 23—Continued
**WORLD CHROMIUM RESOURCES¹ AND ANNUAL PRODUCTION CAPACITY OF CHROMITE ORE,
 FERROCHROMIUM, CHROMIUM METAL, AND CHROMIUM CHEMICALS IN 1991**

(Thousand metric tons, contained chromium)

	Resources ²			Annual production capacity			
	Reserves	Reserve base ³	Identified resources	Ore	Ferro-chromium	Metal	Chemicals
Yugoslavia	NA	NA	NA	3	58	—	5
Zimbabwe	43,500	285,400	285,400	169	136	—	—
Total⁴	418,900	2,086,600	3,441,600	4,193	2,535	25	257

NA Not available.

¹World resources derived in consultation with the U.S. Geological Survey.

²Data and total rounded to nearest 100,000 metric tons.

³The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).

⁴Less than 1/2 unit.

⁵Less than 50,000 metric tons.

⁶Data may not add to totals shown because of independent rounding.

TABLE 24
ALBANIAN CHROMITE PRODUCTION AND EXPORTS

(Thousand metric tons)

Chromite product	Production			Exports		
	1988	1989	1990	1988	1989	1990
>40% Cr ₂ O ₃	337	316	380	280	213	212
30% to 40% Cr ₂ O ₃	226	233	226	188	157	92
16% to 30% Cr ₂ O ₃	147	274	311	43	40	36
Total	710	823	917	511	410	340

Source: Mining Journal, v. 316, No. 8121, pp. 354, 355, May 10, 1991.

TABLE 25
REPUBLIC OF KOREA FERROCHROMIUM IMPORTS,
CONSUMPTION, AND INVENTORY

(Metric tons, unless noted)

	1987	1988	1989	1990	1991
Imports	8,393	13,418	49,965	67,162	99,161
Plant consumption	8,298	10,213	39,731	69,363	97,065
Consumer inventory	1,047	3,290	14,154	11,953	14,049
Consumption percent increase	NA	+23	+289	+75	+40

NA Not available.

Source: Korea Iron and Steel Assoc. as reported by Trade Exploration, Ltd., various issues.

TABLE 26
CHROMITE: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons, gross weight)

Country ²	1987	1988	1989	1990	1991 ^a
Albania	1,075,000	¹ 1,109,000	¹ *1,200,000	¹ 910,000	800,000
Brazil ³	337,500	410,256	475,949	² 267,000	275,000
China ^a	32,000	26,000	25,000	25,000	25,000
Cuba	52,400	52,200	50,600	⁵ 50,000	30,000
Finland ⁴	⁵ 543,000	700,000	498,000	⁴ 489,000	475,000
Greece ⁵	63,825	49,535	⁴ 47,324	⁴ 45,000	45,000
India	623,591	820,863	1,002,659	⁹ 939,000	900,000
Indonesia	—	7,636	7,635	⁸ 8,000	7,000
Iran	⁹ 92,120	⁶ 60,289	⁷ 72,628	⁷ 77,189	80,000
Japan	11,815	9,508	11,674	⁸ 8,075	7,500
Madagascar	106,600	64,177	62,540	¹ *73,000	73,000
Morocco	NA	1,000	1,000	300	500
New Caledonia	61,832	70,341	60,281	6,223	—
Pakistan	10,181	3,327	27,105	¹ 18,191	18,000
Philippines	187,900	¹ 124,258	² 126,562	¹ 183,406	200,000
South Africa, Republic of ⁷	3,789,000	⁴ 4,244,632	4,950,854	⁴ 4,618,310	⁵ 5,078,127
Sudan	13,015	8,000	25,000	¹ 12,500	10,000
Thailand	5	776	416	(⁹)	—
Turkey ⁴	762,071	851,425	¹ 1,000,000	¹ *730,000	800,000
U.S.S.R.	3,570,000	3,700,000	3,800,000	3,800,000	3,800,000
Vietnam ^a	4,000	4,000	3,500	3,500	3,500
Yugoslavia	13,172	11,538	¹ 12,721	¹ 10,843	9,000
Zimbabwe	570,298	561,630	627,424	⁵ 573,103	600,000
Total	¹ 11,919,325	¹ 12,890,391	¹ 14,178,872	¹ 12,847,640	13,236,627

¹Estimated. ²Revised.

³Table includes data available through May 14, 1992.

⁴In addition to the countries listed, Bulgaria and North Korea may also produce chromite, but output is not reported quantitatively, and available general information is inadequate for formulation of reliable estimates of output levels. Figures for all countries represent marketable output unless otherwise noted.

⁵Average Cr₂O₃ content was as follows: 1987—40.0%; 1988—39.0%; 1989—39.5%; 1990—39.2%; and 1991—39.0% (estimated). Brazil also reports run-of-mine crude ore production and Cr₂O₃ content in metric tons as follows: 1987—829,739 (172,215); 1988—779,258 (208,812); 1989-91—not available.

⁶Direct-shipping lump ore plus concentrate.

⁷Reported figure.

⁸Exports of direct-shipping ore plus production of concentrates.

⁹Includes production by Bophathatswana, which was as follows, in metric tons: 1987—522,900; 1988—536,500; 1989—676,154; 1990—468,262 (revised); and 1991—500,000 (estimated).

¹⁰Revised to zero.

TABLE 27
FERROCHROMIUM: WORLD PRODUCTION, BY COUNTRY

(Metric tons)

	1987	1988	1989	1990	1991*
Albania	² 26,300	³ 33,700	³ 38,800	² 24,000	35,000
Brazil	105,394	130,024	113,267	83,753	¹ 82,225
Chile	475	2,212	2,840	2,500	2,000
China	NA	NA	³ 350,000	NA	NA
Czechoslovakia	29,018	29,183	29,844	31,866	30,000
Finland	143,000	156,000	169,000	¹ 152,000	150,000
France	¹ 1,000	¹ 10,000	² 20,000	25,000	20,000
Germany, Federal Republic of ²	71,000	82,000	87,000	² 74,000	71,000
Greece	⁴ 49,000	⁴ 44,150	⁴ 43,500	³ 30,300	25,000
India	¹ 126,227	¹ 140,261	¹ 135,165	¹ 130,000	130,000
Italy	59,045	77,123	81,331	⁴ 41,000	40,000
Japan ⁵	263,988	295,406	324,371	293,345	270,786
Mexico	6,300	9,295	2,569	275	300
Norway ⁶	—	—	—	30,000	90,000
Philippines ⁶	47,000	59,000	69,000	62,000	18,000
Poland	35,900	36,316	² 24,300	13,700	12,000
Romania ⁶	42,000	42,000	42,000	42,000	30,000
South Africa, Republic of ⁷	965,071	993,685	1,036,000	1,022,000	1,127,000
Spain ⁶	16,000	15,000	16,000	15,100	15,000
Sweden	111,815	143,055	151,697	¹ 120,000	110,000
Turkey	52,530	54,030	59,715	⁶ 62,040	78,000
U.S.S.R. ⁴	806,200	925,400	860,800	850,000	800,000
United States ⁵	106,716	119,645	146,844	108,932	68,327
Yugoslavia	56,276	93,349	² 90,428	⁸ 82,687	60,000
Zimbabwe	186,947	224,000	173,000	² 225,102	200,000
Total ^{6,7}	³ 3,307,202	³ 3,714,834	⁴ 4,067,471	³ 3,521,600	3,464,638

*Estimated. ²Revised. NA Not available.

¹Reported figure.

²Includes Eastern and Western states.

³Includes production from Boputhatswana. Includes net production of ferrochromium-silicon if there was any.

⁴Soviet production of electric furnace ferrochromium is not reported; estimates provided are based on crude source material production and availability for consumption (including estimates) and upon reported ferroalloy trade, including data from trading partner countries.

⁵U.S. output of ferrochromium includes high- and low-carbon ferrochromium, ferrochromium-silicon, chromium metal, and other chromium materials.

⁶Data may not add to totals shown because of independent rounding.

⁷Ferrochromium includes ferrochromium-silicon (if any was produced) for Republic of South Africa and the United States.

TABLE 28
CHROMIUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons, contained chromium)

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
WORLD PRODUCTION												
Chromite ore (mine) ¹	2,981	2,736	2,553	2,472	2,943	3,295	3,497	3,588	3,881	4,269	3,889	3,985
Ferrochromium (smelter) ²	1,879	1,760	1,512	1,554	1,862	1,947	1,893	1,882	2,039	2,038	1,965	1,486
Stainless steel, Western World ³	1,171	1,084	1,049	1,185	1,364	1,346	1,395	1,561	1,790	1,733	1,815	1,830
U.S. SUPPLY												
Components of U.S. supply:												
Domestic mines	—	—	—	—	—	—	—	—	—	—	—	—
Secondary	58	65	61	75	79	85	84	95	119	99	94	90
Imports:												
Chromite ore	254	228	130	53	83	109	133	133	185	162	92	65
Chromium ferroalloy	160	228	79	148	223	173	206	171	255	208	244	234
Chromium metal	4	3	2	3	4	4	4	4	4	4	7	6
Chromium chemicals	1	1	2	4	3	5	4	3	2	5	4	5
Chromium pigments	3	2	1	2	2	2	2	2	4	NA	NA	NA
Stocks, January 1:												
Government	1,051	1,051	1,051	1,051	1,051	1,051	1,080	1,110	1,079	1,057	1,097	1,099
Industry	288	219	232	181	164	114	106	102	119	137	139	117
Total U.S. supply	1,818	1,798	1,558	1,518	1,609	1,542	1,619	1,620	1,767	1,673	1,676	1,616
Distribution of U.S. supply:												
Exports:												
Chromite ore	2	18	2	3	15	27	25	(⁴)	1	12	2	3
Chromium ferroalloy	16	7	3	2	9	6	3	2	5	6	5	6
Chromium metal	(⁴)											
Chromium chemicals	9	6	5	5	7	4	7	6	8	6	7	22
Stocks, December 31:												
Government	1,051	1,051	1,051	1,051	1,051	1,080	1,110	1,079	1,057	1,097	1,099	1,166
Industry	219	232	181	164	114	106	102	119	137	139	118	120
Total U.S. distribution	1,297	1,314	1,243	1,226	1,197	1,223	1,247	1,207	1,208	1,260	1,231	1,317
Apparent industry demand	521	483	315	292	412	349	402	382	537	452	447	366

¹Estimated. Revised. NA Not available.

²Calculated assuming chromite ore to average 44% Cr₂O₃ that is 68.42% chromium.

³Calculated assuming chromium content of ferrochromium to average 57%.

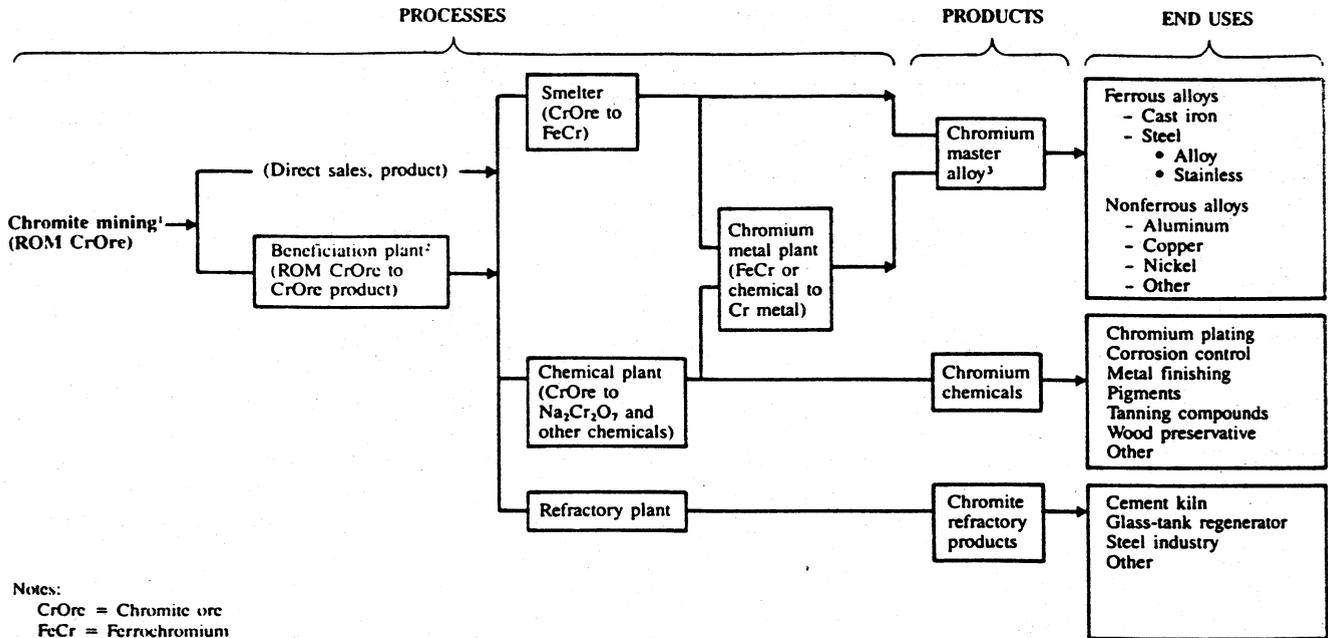
⁴Calculated from World Stainless Steel Statistics, 1991 ed. reported production, assuming chromium content of stainless steel to average 17%.

⁵Nonstockpile-grade material that was included before 1980 was deleted from stockpile count.

⁶Variation in stockpile quantity does not contribute to apparent industry demand because variation resulted from upgrading programs.

⁷Less than 1/2 unit.

FIGURE 1
CHROMIUM MATERIAL FLOW



Notes:

CrOre = Chromite ore
 FeCr = Ferrochromium
 Na₂Cr₂O₇ = Sodium bichromate
 ROM = Run-of-Mine

¹Mining includes screening and hand sorting.

²Beneficiation includes crushing, grinding, and separation techniques, including gravimetric, heavy media, and magnetic.

³Master alloy is an alloy used as a feedstock to produce other alloys.

FIGURE 2
GENERAL RECYCLING CHROMIUM MATERIAL FLOW INDUSTRY STRUCTURE

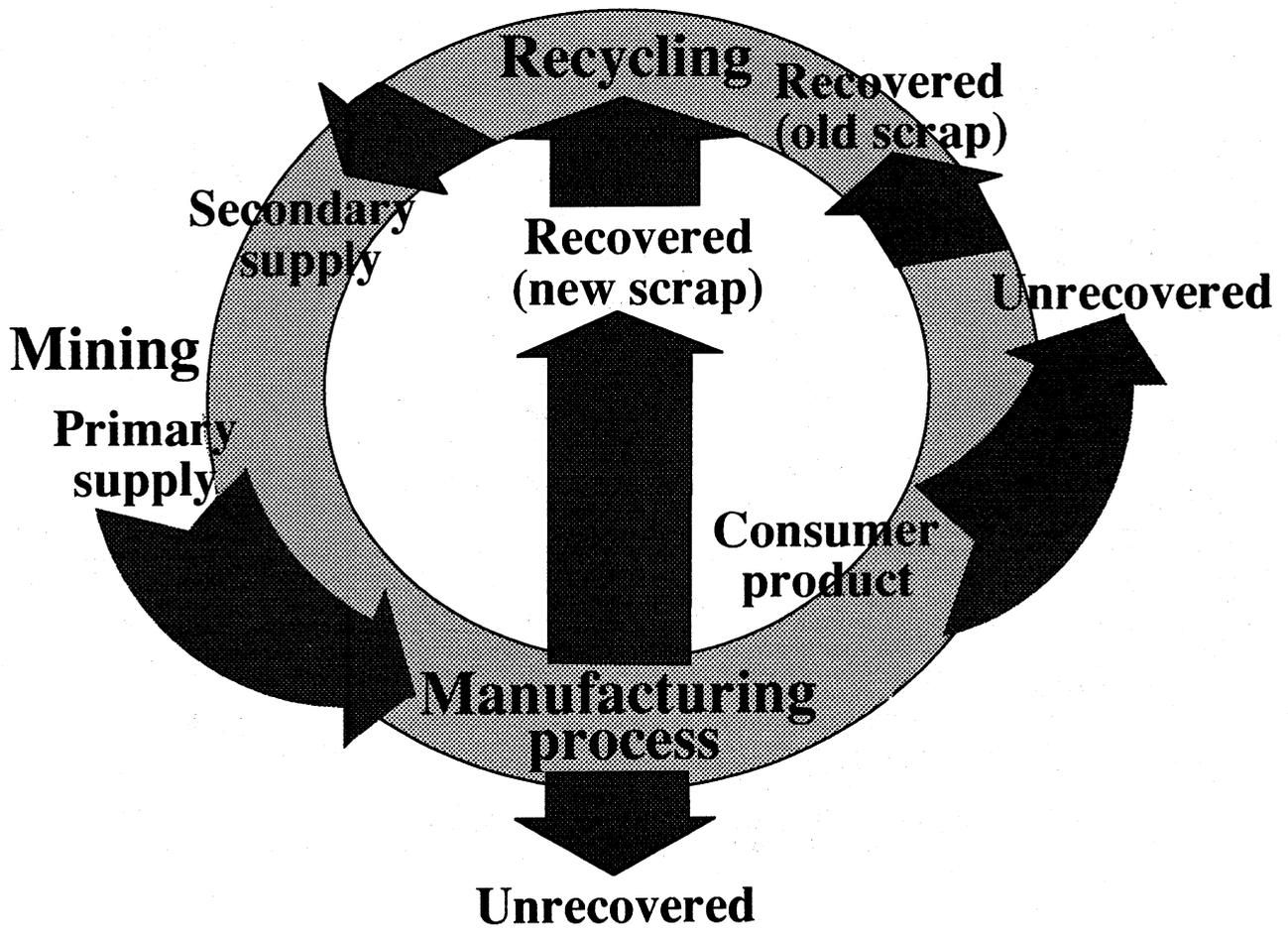
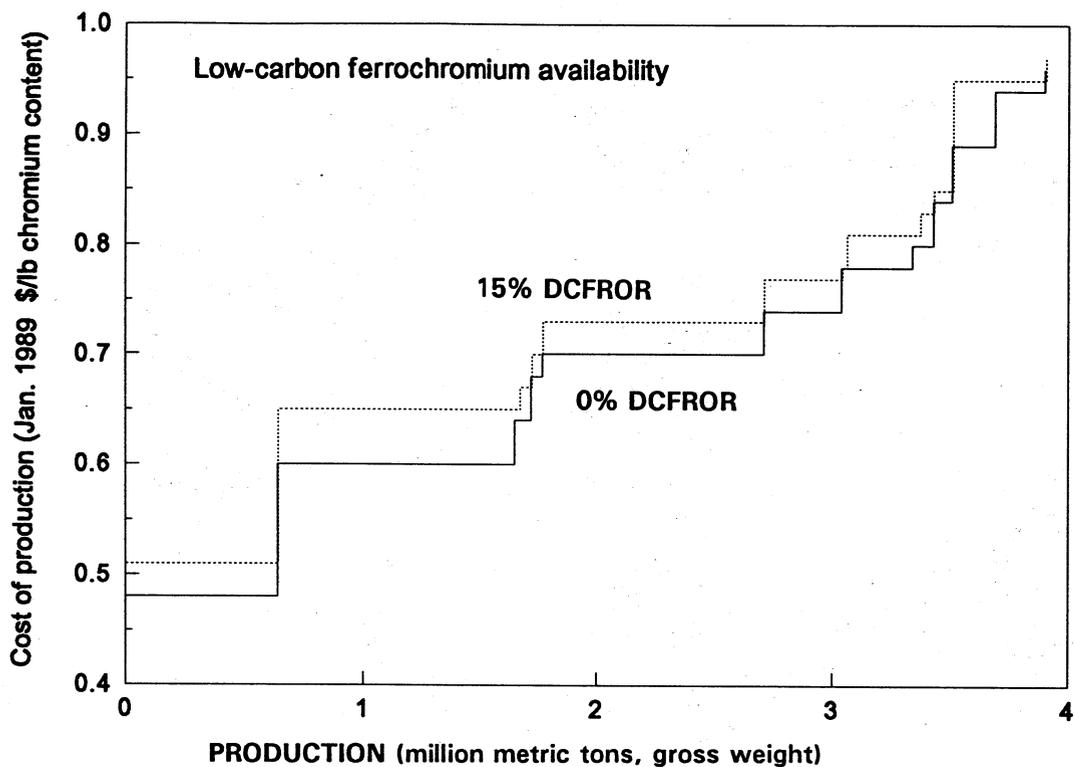
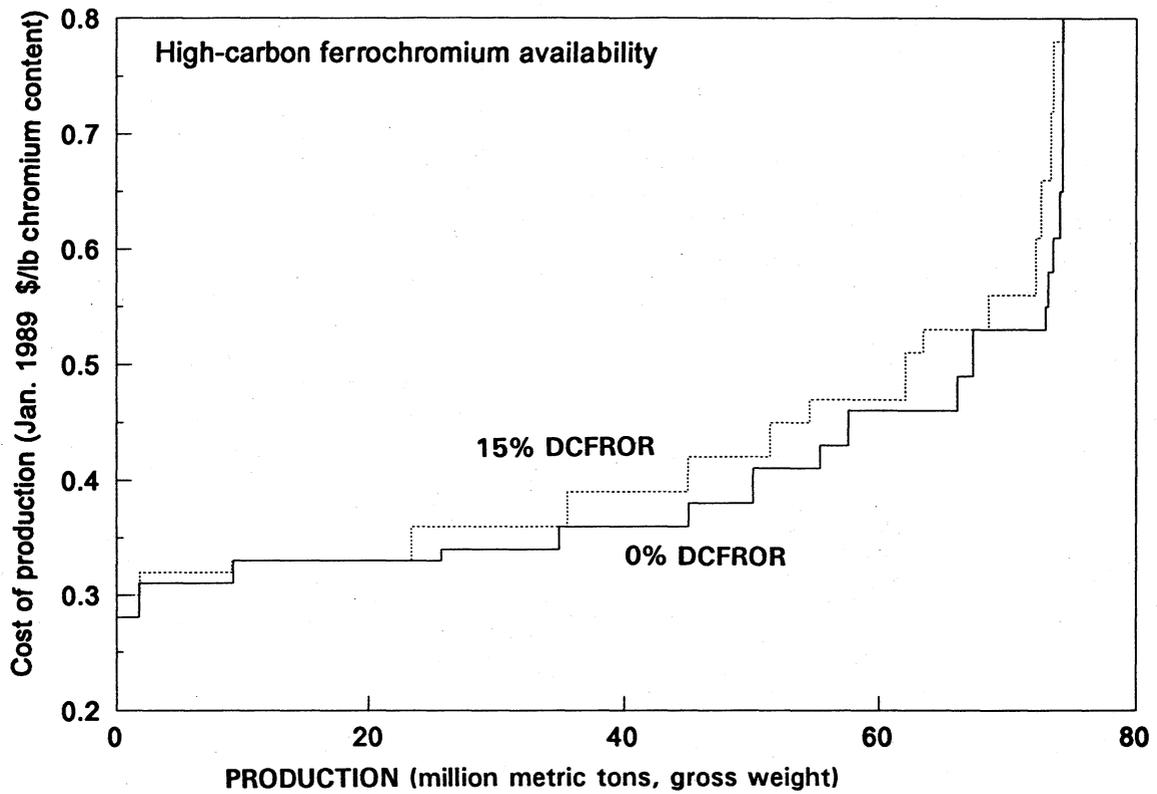


FIGURE 3
COST OF LOW-CARBON FERROCHROMIUM PRODUCTION AT 0% AND 15% DISCOUNTED CASH-FLOW RATE OF RETURN (DCFROR) FOR SELECTED MARKET ECONOMY PRODUCERS



Note: DCFROR is discounted cash-flow rate of return.
Source: U. S. Bureau of Mines, Minerals Availability system cost analysis.

FIGURE 4
COST OF HIGH-CARBON FERROCHROMIUM PRODUCTION AT 0% AND 15% DISCOUNTED CASH-FLOW RATE OF RETURN (DCFROR) FOR SELECTED MARKET ECONOMY PRODUCERS



Note: DCFROR is discounted cash-flow rate of return.
Source: U. S. Bureau of Mines, Minerals Availability System cost analysis.

FIGURE 5
STRUCTURE OF THE JAPANESE CHROMIUM INDUSTRY IN 1991
MAJOR RELATIONSHIPS AMONG JAPAN'S CHROMITE ORE; CHROMIUM FERROALLOY, METAL, AND
CHEMICAL; AND STAINLESS STEEL PRODUCERS

<i>Company structure</i>	<i>Chromite mine</i>	<i>Ferrochromium smelter</i>	<i>Secondary processing</i>
Nippon Steel Affiliate Japan Metals & Chemicals Co. (JMC)		JMC: Oguni Plant (LCFeCr, HCFeCr, & FeCrSi) Kyushu Plant (HCFeCr) Sakata Plant (NP, HCFeCr, & FeCrSi)	
Pacific Metals		Pacific Metals: Hachinohe Plant (HCFeCr)	Pacific Metals: Hachinohe Plant (EF SS)
Nippon Denko		Nippon Denko: Hokuriku Plant (HC FeCr)	Nippon Denko: Hokuriku Plant (AlCrMn) Tokushima Plant (Cr Chm)
Nisshin Steel		(Nisshin Steel) ↑ (20%)	Nisshin Steel: (BF SS) Kure Works Shunan Works
		└ Shunan Denko: └ Shunan Plant (HCFeCr)	
Fuyo Group Showa Denko		↓ (80%) Showa Denko: Chichibu Plant (LCFeCr) Toyama Plant (NP, HCFeCr)	
NKK		NKK: Toyama Plant (LCFeCr, HCFeCr)	NKK: (BF SS) Fukuyama Works Keihin Works
Nippon Steel Corp.			Nippon Steel: (BF SS) Hikari Works Hirohata Works Kimitsu Works Muroran Works Oita Works Yawata Works
Sumitomo Group Sumitomo Electric Industries Sumitomo Metal Industries ↑ Sumitomo Affiliate (34%) Nippon Stainless Steel			Sumitomo Electric Industries: (EF SS) Itami Works Sumitomo Metal Industries: (BF SS) Kashima Works Kokura Works Wakayama Works Nippon Stainless Steel: (EF SS) Naetsu Works
Toyota Motor Affiliate Aichi Steel Works			Aichi Steel Works: (EF SS) Chita Works Kariya Works
Industrial Bank of Japan Group			TOSOH Corp: Hyuga Plant (EiCrMn) Yamagata Plant (Cr Chm)
Mitsui Group Japan Steel Works			Japan Steel Works: (EF SS) Muroran Works Hiroshima Works

FIGURE 5—Continued

STRUCTURE OF THE JAPANESE CHROMIUM INDUSTRY IN 1991.
 MAJOR RELATIONSHIPS AMONG JAPAN'S CHROMITE ORE; CHROMIUM FERROALLOY, METAL, AND
 CHEMICAL; AND STAINLESS STEEL PRODUCERS

<i>Company structure</i>	<i>Chromite mine</i>	<i>Ferrochromium smelter</i>	<i>Secondary processing</i>
Hitachi Ltd. Hitachi Metals			Hitachi Metals: (EF SS) Yakuki Works
Kawasaki Affiliate Tohoku Special Steel			Tohoku Special Steel: (EF SS) Sendai Works
Kawasaki Steel			Kawasaki Steel: (BF SS) Chiba Works Mizushima Works
Sanyo Special Steel			Sanyo Special Steel: (EF SS) Himeji Works
Nippon Yakin Kogyo			Nippon Yakin Kogyo: (EF SS) Kawasaki Works
Kobe Steel			Kobe Steel: (BF SS) Kakogawa Works Kobe Works Nippon Koshuha: (EF SS) Toyama Works
Daido Steel			Daido Steel: (EF SS) Chita Works Hoshizaki Works Kawasaki Works
Nippon Chrome Kogyo	Wakamatsu Mine (Honshu, Chogoku district)		
			Nippon Chemical Industry Tokuyama Plant (Cr Chm)
Awamura Metal		Awamura Metal: Uji Plant (NP, HCFeCr, FeCrSi)	

Key:

Al	Aluminothermic	Cr	Chromium	FeCr	Ferrochromium	Mt	Metal	SS	Stainless steel
BF	Blast furnace	EF	Electric furnace	HC	High carbon	NP	Not producing		
Chm	Chemical	El	Electrolytic	LC	Low carbon	Si	Silicon		

Sources:

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CLAYS

By Robert L. Virta

Mr. Virta, a physical scientist with 16 years of U.S. Bureau of Mines experience, has been the acting commodity specialist for clays since 1991. Domestic survey data were prepared by Maria Arguelles, statistical assistant. The international tables were prepared by Ron Hatch, Douglas Rhoten, and Ted Spittal, international data coordinators.

The amount of clay sold or used by domestic producers increased 3% in tonnage to 44 million metric tons and decreased 7% in value to \$1.5 billion. Production of ball clay, bentonite, and fire clay decreased in 1991. Common clay and shale, fuller's earth, and kaolin production increased. Common clays accounted for 62% of the tonnage, and kaolin accounted for 61% of the value of clays produced in 1991. Imports increased 17% in tonnage to 35,000 tons and 11% in value to \$13 million. Exports decreased 3% in tonnage to 4 million tons and increased 1% in value to \$590 million. (See table 1.)

Clays were produced in 44 States and Puerto Rico. The seven leading producer States, in descending order, were Georgia, Wyoming, Texas, Ohio, Alabama, California, and North Carolina. (See table 2 and 3.)

DOMESTIC DATA COVERAGE

Domestic production data for clays are developed by the U.S. Bureau of Mines from one voluntary survey of U.S. operations. Of the 1,799 operations covered by the survey, 1,240 responded, representing 75% of the total clay and shale production sold or used shown in table 1. (See table 1.)

BACKGROUND

Definitions, Grades, and Specifications

Clays are categorized into six groups by the U.S. Bureau of Mines. The

categories are kaolin, ball clay, fire clay, bentonite, fuller's earth, and common clay and shale. The definitions listed in this work for the high-alumina clays, kaolin, ball clay, and fire clay are similar to those in U.S. Bureau of Mines Information Circular 8335.¹

Kaolin, or china clay, is defined as a white, claylike material composed mainly of kaolinite and other kaolin-group minerals, such as halloysite and dickite. Kaolin has a specific gravity of 2.6 and a fusion point of 1,785° C. Kaolin is classified according to the method of preparation (crude, air-separated, water-washed, delaminated, air-dried, calcined, slip, pulp, slurry, or water suspension) and on specific physical and chemical properties.

Ball clay is a plastic, white-firing clay used mainly for bonding in ceramicware. The clays are of sedimentary origin and consist mainly of the kaolinite, sericite mica, and organic matter. Ball clays usually are much finer grained than kaolins and are renowned for their plasticity. They are classified according to the method of preparation (crude, shredded, air-floated, water-washed, or slurry) and specific physical and chemical properties.

Fire clay is defined as detrital material, either plastic or rocklike, that commonly occurs as underclay below coal seams. Low concentrations of iron oxide, lime, magnesia, and alkalis in fire clay enable the material to withstand temperatures of 1,500° C or higher. It is composed mainly of kaolinite. Fire clays also contain other clays such as diaspore,

burley, burley-flint, ball clay, and bauxitic clay and shale. Fire clays generally are used for refractories or to raise vitrification temperatures in heavy clay products. The fired colors of fire clays range from buffs to grays. Fire clays are classified according to their physical and chemical properties and the characteristics of the products made from them.

Bentonite is a clay composed primarily of smectite minerals. The primary smectite mineral is usually montmorillonite. Swelling-type bentonite has a high-sodium ion concentration. Its volume increases 15 to 20 times its dry volume when wetted with water. Nonswelling bentonites usually are high in calcium. Bentonite is classified according to its physical and chemical properties, with particular emphasis on particle size and swelling index.

The term "fuller's earth" is derived from the first major use of the material, which was for cleaning textiles by fullers. Fuller's earth does not refer to a clay with a specific composition or mineralogy. It is defined as a nonplastic clay or claylike material, usually high in magnesia, that is suitable for decolorizing and purifying mineral and vegetable oils. They are composed mainly of the needle- and/or lath-shaped clay mineral attapulgite or varieties of montmorillonite. Fuller's earths containing opal or other forms of colloidal silica also are produced. Fuller's earths are classified according to their physical and chemical properties. Sepiolite-type clays are grouped with

fuller's earths under the Bureau classification system.

Common clay is defined as a clay or claylike material that is plastic enough to mold easily. Its vitrification point is usually below 1,100° C. Shale is a laminated sedimentary rock that is formed by the consolidation of clay, mud, or silt. The common clays and shales are composed mainly of illite or chlorite. They also may contain kaolin and montmorillonite. Common clays and shales usually contain more alkali, alkaline earth, and ferruginous minerals and less aluminum than high-quality kaolins, fire clays, and ball clays. Iron present in the clay usually imparts a reddish color to the final product after firing. There is no formal classification of common clays and shales, although a clay may sometimes be referred to as common, brick, sewer pipe, or tile clay. Clay and shale are used in the manufacture of structural clay products such as brick, drain tile, portland cement clinker, and expanded lightweight aggregates.

The American Society for Testing and Materials, American Foundrymen's Association, American Oil Chemist's Society, American Petroleum Institute, Technical Association of the Pulp and Paper Industry, and other national organizations have developed tests and set standards for some applications. Many producers and consumers, however, use nonstandardized tests that are applicable to their specific needs. Individual companies often set the acceptable limits of mineralogical composition, particle size, and other physical and chemical properties. Detailed data on specifications have been published by the U.S. Bureau of Mines.²

Products for Trade and Industry

Because of the many types of clay and different qualities within each type, the consumption pattern and the products for trade and industry are constantly changing. Consumption of kaolin in refractories has been growing since 1970 because of the increasing popularity of castable, ramming, gunning, and plastic

mixes that use calcined kaolin aggregates (grog) in their formulations.³ The consumption of calcined kaolin grogs also has increased in refractory brick manufacturing, replacing imported calcined refractory-grade bauxite grogs. Bentonite products for waterproofing and sealing in construction and reservoir uses also have gained in popularity. Attapulgite-type fuller's earth production, like bentonite, is finding increasing applications in the premium drilling mud industry.

Industry Structure

An estimated 319 companies operating more than 1,000 clays pits or mines reported production in 1991; of these, 103 companies, most with multiple operations, accounted for approximately 66% of the tonnage and 75% of the value for all types of clay produced and sold or used. Clay production was reported in all States and Puerto Rico except Alaska, Delaware, Hawaii, Rhode Island, Vermont, Wisconsin, and the District of Columbia.

The leading clay-producing States were Georgia, 9.5 million tons; Wyoming, 2.5 million tons; Texas, 2.3 million tons; Ohio, 2.2 million tons; Alabama, 2.1 million tons; North Carolina, 2.1 million tons; and California, 2.1 million tons. (See table 2.) Most of the clay is mined by open pit methods. Less than 2% of U.S. clay output is from underground mines in 1991. Most of the underground production is in Pennsylvania, Ohio, and West Virginia, where the clays are mainly underclays associated with coal and suitable for refractory uses.

Forty-two firms operated 141 kaolin mines in 14 States. In 1991, three large, diversified firms accounted for about 60% of total domestic kaolin output. Most large kaolin producers have operations in Georgia, which accounted for 79% of the kaolin production.

The ball clay industry is small, with 6 producers operating 36 mines in 5 States in 1991. Three of the producers were large, diversified firms with widespread foreign and domestic mineral interests.

Tennessee ball clay production represented about 66% of the total output.

Fireclay producers were mostly refractories manufacturers that used the clay in firebrick and other refractories. Seventy-eight mines were operated in 1991 by 19 firms in 7 States.

Firms producing bentonite operated 144 mines in 11 States. Four producers were large, diversified firms with international mineral operations; three of the firms had interests in other types of clay in the United States. Wyoming was the leading State, accounting for 73% of the total output. Swelling-type bentonite is produced mainly in Montana and Wyoming and nonswelling-type bentonite is produced in Mississippi and Texas. The United States is the world's largest producer and exporter of bentonitic clays.

Nineteen companies produced fuller's earth from 37 mines in 10 States. Eleven of the mines were in the attapulgite-fuller's earth areas of Florida and Georgia. These two States accounted for 35% of domestic production. Most producers were small, independent firms, but three were large, diversified corporations with international mineral interests. The world's fuller's earth needs are supplied from relatively few areas. The United States is the world's largest producer and user of fuller's earth.

Firms producing common clay and shale in 1991 were manufacturers of structural clay products, clay pipe, lightweight aggregates, and cement. Most companies mined the clays used in making their products. Private mining contractors and haulers were employed in many of the operations. Some producers were diversified firms having interests in metals and other nonclay products. Some companies owned and operated several clay pits and plants in order to cover a large market area. The economic radius for shipment of common clay or shale products is usually 200 miles or less. The high cost of transport promotes the development of local ownership companies, or in the case of a large firm, the ownership and operation of several strategically located pits and associated fabricating plants.

Geology-Resources

Clay is formed by the mechanical and chemical breakdown (weathering) of rocks. The weathering products consist of mineral grains and rock fragments of different size and different physical and chemical properties. The nonplastic portion consists of altered and unaltered rock fragments (grit), which are usually quartz, micas, feldspar, and iron oxides. The plastic portion usually is composed of clays and is low in grit.

Clays may be classified as residual or sedimentary. Residual clays are deposited in the same location in which they were formed. Sedimentary clays are those that have been transported, usually by water, and deposited elsewhere.⁴ Sedimentary clays often undergo further alteration and classification during transport. Kaolin deposits in Georgia and South Carolina are sedimentary. Kaolin deposits in North Carolina and English china or kaolin clay deposits are residual.⁵ The Kentucky and Tennessee ball clays and the Missouri fire clays are sedimentary deposits. Most bentonites, montmorillonites, and fuller's earth were formed in place through the weathering of volcanic ash or tuff. The attapulgite-type fuller's earth deposits of Florida and Georgia were probably not formed from volcanic ash or tuff. Geologists have never found any evidence of volcanic materials associated with these deposits.⁶

The definitions of reserves and reserve base are published in U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals." Reserves are the part of an ore body that can be economically extracted at the time of evaluation. Reserve base is the part of an ore body that meets specified minimum physical and chemical criteria related to current mining and production practices. Reserve base includes reserves, marginal reserves, and subeconomic resources.

Common clays and shale deposits are found throughout the United States. Clays and shale were mined commercially in 43 States and Puerto Rico. Domestic resources are almost unlimited. Not all deposits, however, are near potential

markets, and most deposits are not suitable for all applications. For example, most common clay or shale deposits can be used to manufacture common brick, but the color or strength of the final product may not meet the requirements of the local market. Relatively few deposits are suitable for manufacture of lightweight aggregate. Even with these limitations of location and use, resources of common clay and shale are "virtually unlimited."

U.S. reserves of other types of clays that are owned or controlled by domestic producers are estimated to be about 700 million tons. U.S. reserves of kaolin are estimated to be 400 million tons; ball clay, 30 million tons; fire clay, 100 million tons; bentonite, 120 million tons; and fuller's earth, 60 million tons.

Large quantities of high-quality kaolin suitable for paper-coating and paper-filler are found in Georgia. A small area in Florida and Georgia contains sizable reserves of attapulgite-type fuller's earth. Most bentonite for iron ore pelletizing and oil-well-drilling muds is mined in Wyoming. Fire clay deposits, such as those found in Missouri, are widespread. Deposits of high-quality fire clay are nearing depletion. Kentucky and Tennessee are two of only a few States that have sizable deposits of ball clay.

Technology

Exploration.—Exploration begins with an understanding of the geological occurrence of the clays of interest. With this knowledge, potential economic deposits can be located. Auger or core drills are then made to delineate the size and shape of the deposit and to obtain material for testing.

Kaolins usually are evaluated for filler and ceramic applications. The grit, particle size, brightness, and leachability are determined. Air-floated clays normally require only grit and brightness determinations. Kaolin, ball clay, and fire clay for ceramic and/or refractory applications are analyzed for grit, brightness, green and dry strengths, fired color, and iron and alumina contents. The common clays and shales usually are

tested according to the intended end use, such as brick, structural-drain tile, or lightweight aggregate. Usually, prepared specimens are tested for plasticity, green strength, shrinkage, vitrification temperature range, etc. For lightweight aggregates, the bloating range is determined. Bentonites and fuller's earth clays are difficult to evaluate because there is no standard testing procedures or specifications. Generally, they are processed to meet the purchaser's specifications.

Mining.—Most clays are mined from open pits using modern surface mining equipment such as draglines, power shovels, front-end loaders, backhoes, scraper-loaders, and shale planers. Some kaolin is extracted by hydraulic mining and dredging. A few clay pits are operated using crude hand-mining methods. A small number of clay mines, principally in underclays in coal mining areas, are mined underground using room-and-pillar methods. Clays usually are transported by truck from the pit or blending areas to the processing plants. Rail, conveyor belt, and in the case of kaolin, pipelines also are used.

About 100% of the clay is recovered from the minable beds in most open pit operations. Approximately 75% is recovered in underground operations. The waste-to-clay ratio is highest for kaolin, about 7:1, and lowest for common clay and shale, about 0.25:1.

Processing.—Clays are used in a large number of products so they must be treated in many different ways. Processing can consist of very simple and inexpensive crushing and screening for some common clays. It also can consist of very elaborate and expensive grinding, sizing, bleaching, delamination, etc., for paper-coating clays and high-quality filler clays for use in rubber, paint, plastic, and other products. In general, processing does not appreciably alter the chemical or mineralogical characteristics of the clays. The two exceptions are calcining and cation exchange.

Significant processing losses occur with kaolin and fuller's earth. About 40% of the kaolin and 30% of the fuller's earth delivered to the processing plants is discarded. Waste material from processing consists mostly of off-grade clays and small quantities of quartz, mica, feldspar, and iron-bearing minerals.

Kaolin.—Processing involves one or more of the following: crushing, blunging with dispersant, rough sedimentation, water fractionation, magnetic separation, ultraflotation, acid treatment, calcination, air floating, and attrition grinding, slurring, and delaminating. Kaolins used for paper-coating applications may be bleached and further delaminated by grinding, deflocculation, and elutriation to special sizes. Ultraflotation or wet magnetic separation treatment may be used to remove iron- or titanium-bearing minerals to obtain a whiter product.

Ball Clay.—Processing involves drying, shredding, pulverizing, air floating, and slurring.

Fire Clay.—Processing involves crushing, calcining, and blending.

Bentonite.—Processing involves weathering, drying, grinding, sizing, granulation, and the use of additives for cation exchange.

Fuller's Earth.—Processing involves blunging, extruding, drying, crushing, grinding, sizing, and dispersing.

Common Clay and Shale.—Processing involves crushing, blunging, extruding, and drying. Common bricks, tile, lightweight aggregate, etc., require firing in a kiln. The kiln firing or drying operation produces a finished manufactured product.

Processing costs for clays range from a few cents per ton for some common clays to more than \$400 per ton for some special paper-coating clays and high-

quality clays that require very elaborate and expensive treatments.

Price schedules, although not complete, are available and are published regularly in trade journals such as the American Paint and Coatings Journal, Chemical Marketing Reporter, and Industrial Minerals (London).

Federal tax laws allow clay producers a depletion allowance on both domestic and foreign gross income not to exceed 50% of net income with depletion deduction. Depletion allowances are as follows: ball clay, bentonite, kaolin or china clay, sagger clay, and clay used or sold for purposes dependent on its refractory properties, 14% domestic and 14% foreign; fuller's earth, 14% domestic and 14% foreign; clay used for extraction of alumina or aluminum compounds, 22% domestic; clay used or sold for use in manufacturing drainage and roofing tile, flower pots, and kindred products, 5% domestic and 5% foreign; and clay and shale used for making brick, tile, and lightweight aggregate, 7.5% domestic and 7.5% foreign. Severance taxes are levied by some producing States.

Byproducts and Coproducts

Firms in California, Florida, and Texas produce silica glass sand as a coproduct of its kaolin production. Flake mica is a byproduct in one kaolin operation in North Carolina. Bauxite is a coproduct in kaolin operations in Alabama and Georgia. Clay and limestone for cement manufacture are often produced from the same property and reported as coproducts or byproducts even though they are usually mined separately from different formations or beds. Sand, gravel, and stone aggregates are occasionally produced together with common clays.

Economic Factors

Economic factors affecting clays vary in importance with type, quality, and intended end use. The cost of transportation is an important factor for the common clay and fire clay industries;

mines must be close to consumers to be cost competitive. Other types of clays are less abundant and have higher unit values. They can be shipped greater distances from the mines and still be cost competitive. For example, paper-coating clay from Georgia and attapulgitic-type fuller's earth from Florida and Georgia can be shipped nationwide. Bentonite for iron ore pelletizing from Montana and Wyoming can be shipped a considerable distance to the iron ore centers. In some of these cases, the shipping costs exceed the value of the clays at the mine or processing plant.

Because most clays are relatively low-cost materials in the crude state, mining costs must be kept as low as possible. Cost of the crude clays ranges from less than \$3 per ton for some common clays to more than \$20 per ton for some of the higher quality materials.

Very little clay is imported because transportation costs would make the clays noncompetitive in price. Consequently, import duties have little impact on the amount of clays imported.

Operating Factors

To manufacture finished clay products, producers require equipment to mine and process the crude clay and a kiln for firing or drying their products. Mining, processing, and manufacturing are all energy-intensive operations. Many clay producers converted to coal from oil firing and gas firing. However, the conversion to coal and/or wood as a kiln fuel is gaining in popularity where feasible in heavy clay and refractory products manufacturing and in bentonite processing.

Losses in mining are extremely small, except in underground mining where recovery will average about 75%. Processing losses for material receiving, crushing, grinding, mixing, shredding, blending, and drying also are insignificant. Losses from washing, sizing, etc., reach 30% or 40%.

Clay mining lacks many of the hazards associated with other types of mining because only a few deposits require the use of explosives and most mines are

open pit earth-moving operations. Domestic mine employment in 1991 was estimated to be 2,000 workers. Domestic mill employment was estimated to be 9,100 workers.

ANNUAL REVIEW

Issues

Clay mining has an environmental impact because of the disturbance to the land. Overburden is moved and clays are removed, leaving a depression or pit. State laws usually require leveling or recontouring of the disturbed area and planting trees or grasses to minimize erosion. For processing, the impoundment of slimes and dust control are usually required. The rules for disposal of coarse tailings are similar to or included with those laws governing reclamation of the mined area.

Many local governments are enacting stricter regulations. In some cases they change the land use zoning. New regulations and land use changes sometimes force a mine to close or relocate to a more distant deposit, increasing costs to the community because of increased transportation charges.

An issue that continues to interest a segment of the clay industry is the classification of crystalline silica as a probable human carcinogen. Mineral products containing 0.1% or more crystalline silica must be labeled in accordance to the Occupational Safety and Health Administration's Hazard Communication Standard (HCS), and employers must comply with the terms of HCS with regard to worker training. Some States are enacting stricter regulations with regard to crystalline silica based on the health findings.

Although domestic clay resources are more than adequate and clay is a mature industry, the average price for clays is expected to rise steadily. The increased prices reflect the demand for higher quality specialty clay by consumers and increased costs associated with land acquisition, severance taxes, land rehabilitation, energy requirements, and

environmental factors. These rising prices, if unchecked, will have an adverse affect on the clay industry by making competing materials more cost competitive.

Production, Prices, and Foreign Trade

ECC Group PLC, United Kingdom, announced the sale of Southern Clay Products Inc. to Laporte PLC. Southern Clay Products mines ball clay from a mine near Gonzales, TX, and bentonite from a mine in Kaycee, WY.⁷

Approval was granted for the expansion or creation of several mines, including a kaolin mine near Belview, MN, and common clay operations near Lewiston, ME, and Quinton, NJ.⁸

Kaolin.—Domestic production of kaolin increased 5% to 9.5 million tons. The value of production decreased 3% to \$9.2 billion. The unit value of kaolin decreased 8% to \$96 per ton. Filler- and refractory-grade kaolin had the highest reported values. Kaolin was produced in 14 States. Georgia accounted for 79% and South Carolina accounted for 6% of total production. Georgia accounted for more than 94% of the total production value. (See table 4.) Filler, refractory, chemical- and water-washed, air-floated, and unprocessed grades were produced in Georgia. South Carolina produced only air-floated and unprocessed grades of kaolin. (See tables 5, 6, 7, 8, 9, and 10.) Arkansas and California produced refractory- and chemical-grade kaolins. Kaolin producers reported major domestic end uses as paper-coating, 34%; paper-filling, 14%; refractories, 21%; fiberglass and insulation, 5%; face brick and rubber, 3% each; and paint and chemicals, 3%. (See table 11 and figure 1.)

Asea Brown Boveri Inc. sold Dry Branch Kaolin Co. to Imetal. The Dry Branch operation produces kaolin for the ceramics, ink, paint, paper, and rubber industries.⁹

Despite the overall slow economy, kaolin production increased. Domestic sales of paper-grade kaolin decreased 5%

from those of 1990. However, the trend toward the use of high-quality coated papers resulted in a growth of 4% for coating clay. Exports increased 35% because of a continued weak U.S. dollar. U.S. sales of unprocessed kaolin declined 35% because of the completion of a major project that required large tonnages of low-value unprocessed kaolin. Calcined and water-washed kaolin production increased 76% and 9%, respectively. This contrasts with an 18% decrease in sales of delaminated and 21% decrease in sales of air-float kaolin. (See tables 5, 6, 7, 8, 9, 10, and 11.)

Exports of kaolin reported by the U.S. Department of Commerce increased 1% to 2.86 million tons valued at \$430 million. The unit value of the exported kaolin decreased slightly to \$150.71 per ton. Kaolin, including calcined material, was exported to 65 countries. The major importers, in descending order, were Japan, Canada, Finland, the Netherlands, Italy, and Mexico. Kaolin producers reported end-use markets for their exports as follows: paper-coating, 68%; paper-filling, 20%; rubber, 2%; and other, including ceramics, paint, and refractories, 9%. (See tables 11 and 26.)

Kaolin imports for consumption increased about 1% to 3,373 tons valued at \$1.6 million. The unit value increased about 7% to \$476.43 per ton, reflecting the continuing strong worldwide demand for premium-quality kaolin. (See table 27.)

Kaolin prices quoted in the trade journals generally were unchanged from those of the previous year. (See table 12.)

The Food and Drug Administration amended the food additive regulations to allow the use of modified kaolin in paper and paperboard intended for use in contact with food.¹⁰

Ball Clay.—Production of domestic ball clay decreased 1% to 784,000 tons valued at about \$33 million. Tennessee supplied 66% of the Nation's output, followed by, in descending order of production, Kentucky, Mississippi, Texas, and Indiana. Production decreased in all the major producing

States. The principal ball clay markets were dinnerware, floor and wall tile, and sanitaryware. (See tables 13 and 14.)

The average unit value for ball clay reported by domestic producers increased slightly to \$42.63 per ton. Listed prices in the Chemical Marketing Reporter, January 6, 1992, per short ton, were unchanged from those of 1991. (See table 12.)

Ball clay exports decreased 16% to 58,000 tons valued at \$2.9 million. The unit value increased to \$50.15. Shipments were made to 24 countries. The major importer was Mexico, with 79% of the exports. (See tables 14 and 26.)

Ball clay imports for consumption, almost entirely from the United Kingdom, also decreased 53% to 750 tons valued at \$262,000. The unit value of these clays increased more than 21% to \$347.94 per ton. (See table 27.)

Fire Clay.—Fire clay sold or used by domestic producers decreased 24% in tonnage to 474,000 tons and 18% in value to \$13.1 million. Missouri was the leading producing State followed by Ohio, Alabama, New Jersey, Pennsylvania, and New Mexico. (See table 15).

The clay refractory industry had been in a period of low production because of decreased demand brought about by technological changes and lower consumption levels by its major users—steel, nonferrous metals, ceramics, glass, and minerals processing industries. The technological changes in steelmaking, away from integrated pig iron systems and toward electric furnaces and/or minimills, further compounded the problem by employing shapes and specialty refractories requiring less fire clay.

Fire clay was produced from mines in six States. Missouri, Ohio, and Alabama, in descending order of volume, accounted for more than 89% of the total domestic production.

North American Refractories Co. merged with Didier Taylor Refractories Corp. The combined companies will

operate under the North American Refractories name.¹¹

Exports of fire clay decreased 7% to 199,000 tons. The unit value of exported clay increased 9% to \$95.48 per ton. Fire clay was exported to 33 countries. The major recipients, in descending order, were the Netherlands, Mexico, Japan, Australia, and Taiwan. Fire clay imported from two countries amounted to 425 tons valued at \$80,000. (See tables 26 and 27.)

The unit value for fire clay, reported by producers, ranged from about \$5 to \$43 per ton.

Bentonite.—Bentonite production decreased more than 3% to 3.4 million tons, while the value increased 2% to \$125.4 million. Wyoming was the largest bentonite producer, accounting for 73% of production. Wyoming also was the leading producer of swelling bentonite. (See table 16.) The three major end uses were drilling mud, foundry sand, and iron ore pelletizing with 20%, 17%, and 21%, respectively, of total sales. Sales of bentonite to the foundry sand and iron ore pelletizing industries increased 5% in 1991. (See figure 17.)

For the past 2 years, bentonite producers have reported that about 700,000 tons of bentonite was sold to the iron ore pelletizing industry, more than that in previous years. Domestic bentonite consumption, based on data provided by the domestic iron ore pelletizing industry, was estimated to be between 510,000 and 520,000 tons. Bentonite exports to Canadian iron ore pelletizers were estimated to be between 110,000 to 130,000 tons, making sales to U.S. and Canadian pelletizers between 620,000 to 650,000 tons. Bentonite also was exported to other countries for pelletizing iron ore.

Bentonite was produced in 11 States. Most of the high-swelling or sodium bentonite was produced in Wyoming. Mines in Alabama and Mississippi produced more than one-half of the low-swelling or calcium bentonite. Calcium bentonite produced in Alabama and

Mississippi was suitable for the production of absorbent, acid-activated, and foundry products. (See table 16.)

American Colloid Co. built a new blending facility in Alabama. The facility processes bentonite for use by the foundry industry.

The quoted price in the Chemical Marketing Reporter, January 6, 1992, for domestic bentonite, carload lots, f.o.b. mines, was \$28.60 per ton. The average unit value reported by domestic producers increased 3% to \$36.54 per ton.

Bentonite exports decreased 6% to 660,000 tons valued at \$63.6 million. The unit value of exported bentonite increased about 18% to \$96.32 per ton. Bentonite was exported to 61 countries, 37 more than those in 1990. The six major recipients, in descending order, were Japan, Canada, Taiwan, United Kingdom, Venezuela, and Australia. Domestic bentonite producers reported their exports were foundry sand, 62%; drilling mud, 24%; and others, 14%. (See tables 17 and 26.)

Bentonite imports for consumption consisted mostly of untreated bentonite clay and chemically or artificially activated materials. Bentonite imports increased 9% to 2,224 tons. Canada was the largest supplier of bentonite. The chemically activated category decreased 3% to 1,084 tons valued at \$1.8 million. Mexico accounted for 62% of the chemically activated bentonite imported into the United States. This was an increase of 9% over that of 1990. (See table 27.)

Fuller's Earth.—Production of fuller's earth increased 19% to 2.74 million tons valued at \$270 million. Reported production of fuller's earth is greater than that of 1990 because two producers were included under the fuller's earth category for the first time. They were reported under other clay categories in the past. The average unit value increased 2% to \$98.70 per ton. Production was reported in 10 States. Florida and Georgia accounted for nearly one-half of domestic production. Pet waste absorbents

accounted for 65% of consumption. (See table 18 and figure 3.)

Production from the region that includes Attapulugus, Decatur County, GA, and Quincy, Gadsden County, FL, is composed predominantly of the lathshaped amphibolelike clay mineral attapulugite. Most of the fuller's earth produced in other areas of the United States contains varieties of montmorillonite and/or other clays.

Attapulugite, a fuller's earth-type clay, finds wide application in both absorbent and gelling and/or thickening areas. The thixotropic properties of attapulugite clays provide the important thickening and viscosity controls necessary for suspending solids. Mineral thickeners are used in such diverse markets as paint, joint compound cement, and saltwater drilling mud.

Fuller's earth was exported to 29 countries, 1 less than that in 1990. The quantity decreased 59% to 27,000 tons. The unit value of exported fuller's earth increased 27% to \$164.44. The increase was attributed to a larger percentage of high-cost gelling and drilling mud grades shipped. Most of the fuller's earth was shipped to Canada (22%) and the Netherlands (33%). Small amounts of decolorizing fuller's earth were imported from Canada and the Federal Republic of Germany. (See tables 19, 26, and 27.)

Common Clay and Shale.—Domestic sales or use of common clay and shale increased 5% in tonnage to 27.2 million tons and increased 4% in value to \$141 million. Of the nine major producing States, production increased in Alabama, California, Michigan, Missouri, South Carolina, and Texas and decreased in Georgia, North Carolina, and Ohio. Common clay and shale represented about 62% of the quantity but only 9% of the value of total domestic clay production. (See table 20.)

Domestic clay and shale are generally mined and used captively to fabricate or manufacture products. Less than 10% of the total output is usually sold. The average unit value for all common clay and shale produced in the United States

and Puerto Rico decreased 11% to \$5.18 per ton. The reported unit value ranged from \$2 per ton to \$36 per ton.

Consumption and Uses

The manufacture of heavy clay products, including (1) building brick; sewer pipe; and drain, roofing, structural, terra cotta, and other tile; (2) portland cement clinker; and (3) lightweight aggregate, accounted for 29%, 23%, and 8%, respectively, of total domestic consumption. (See table 21.)

Kaolin has many industrial applications, and many grades are specifically designed for use as a filler in paper, paint, rubber, plastics,¹² and ceramics.¹³ New uses are constantly being developed. Kaolin is a unique industrial mineral because it is chemically inert over a relatively wide pH range, is white in color, and has good covering or hiding power when used as a pigment or extender in coated films and filling applications. It also is soft and nonabrasive, has low conductivity of heat and electricity, and costs less than most materials with which it competes. Fillers and extenders must meet very rigid specifications such as particle size, color, brightness, and viscosity.¹⁴

Ball clays are extremely refractory and their use, largely in whitewares, imparts a high green strength as well as plasticity to the bodies. Although white-firing ball clays are preferable, fired products that range to cream or buff colors do not generally impair the quality of the whiteware products.

Fire clays are used mostly in commercial refractory products such as firebrick and block of many shapes, insulating brick, saggars, refractory mortars and mixes, ramming and gunning mixes, grog and crude aggregates, and many other products. Fire clays are also added to common clays to increase the vitrification range of sewer pipes and bricks.

The swelling sodium bentonites are used largely in drilling muds, in foundry sands, and in pelletizing taconite iron ores. The nonswelling or calcium bentonites are used mostly in conjunction

with the swelling bentonites in foundry sand mixes in which the sodium bentonites provide dry strength and the calcium bentonites provide high green strength. Fuller's earth and calcium bentonites find application in decolorizing and purifying mineral, vegetable, and animal oils. Clays used to process animal or vegetable oils usually are activated by acid treatment. Acid treatment produces a highly absorbent sievelike structure. Attapulugite is used in drilling muds instead of sodium bentonites for drilling saltwater formations. Sodium bentonite flocculates in brine, thereby destroying the colloidal suspension required for drilling. The major uses for attapulugite and montmorillonite types of the fuller's earths are in pet waste and oil and grease absorbents because of their absorbent properties.

Bentonite also is used for foundry casting by the steel, iron, and nonferrous casting. The bentonite provides good green strength and desirable dry strength characteristics. Sodium bentonites are used in steel casting. Ion-exchanged bentonites are used for iron and nonferrous casting. There is increased use of mixtures of ion-exchanged and sodium bentonites to meet the more stringent demands of the casting industry.¹⁵

Construction.—Common clays and shales are used to manufacture a wide variety of construction materials such as structural clay products, cement, and expanded aggregates.

Structural Clay Products.—Structural clay products such as building brick, drain tile, and vitrified sewer pipe are used in building construction, for sewer systems, to drain farmers' fields, and for many other uses. Other clays, such as kaolin, fire clay, or ball clay, could in many cases be used to produce equally suitable "heavy clay" products, but they are generally more refractory and valuable for other uses. Of the total clay produced, about one-third is consumed in the manufacture of these structural products.

Hydraulic Cement.—The portland cement industry requires alumina and silica as constituents in the manufacture of portland cement. Common clays provide a low-cost source of these materials.

Expanded Clay and Shale.—For this purpose, certain bloating qualities and strength are required. Lightweight concrete blocks, floors, walls, and other shapes made from expanded clay and shale have a lower overall weight, which results in savings in the design of the supporting framework. Also, products made from expanded clay and shale have better insulating qualities than equivalent products made with sand and gravel and crushed stone aggregates.

Refractories.—Refractories require strength at high temperatures, resistance to corrosion, low coefficient of expansion, and many other physical and chemical properties, depending on the application. Clays with physical properties most suitable for general refractory use have been classed as fire clays. The current trend is for refractories designed for a specific use and castable mixes containing refractory aggregates and calcium aluminate cements.¹⁶

Paper Products.—Demand for clays for use as filler and coater in paper has followed the rapid increase in demand for paper. Kaolin is the principal clay used.

Other Uses.—Pottery and related products require good ceramic qualities, including plastic formation, desirable firing temperatures, color, etc. The principal clays meeting these and other specifications are ball clay and kaolin. Kaolin also is used as a raw material feed in formulating bottle and plate glass batches. Drilling mud is a scientifically designed mixture of several items. It contains, in addition to bentonite or attapulgite, ground barite for its high specific gravity.¹⁷ Demand for bentonite in iron and steel production is based on

its ability to form strong iron ore pellets from fine-grained taconite concentrates. Easily handled hard pellets are essential for efficient blast furnace operation.

Heavy Clay Products.—The value reported for shipments by the Bureau of the Census for heavy clay products decreased 20% to \$1.4 billion. The million standard brick count for building or common face brick decreased 20%. Shipments of clay floor and wall tile decreased 16% while vitrified clay and sewer pipe fittings decreased 15%. (See tables 22 and 23.)

Lightweight Aggregates.—Consumption of clay and shale in the production of lightweight aggregate decreased 5% to 3.6 million tons. Concrete block, the largest category, (67% of total production), decreased 3% while the second biggest consuming area, structural concrete (20% of total production), decreased 10%. The third largest segment, highway surfacing (8% of production), increased slightly. The other category, the smallest segment consisting essentially of market areas such as recreational and horticultural uses, decreased 20%. (See table 24.)

Refractories.—All types of clay, except for fuller's earth, were used in manufacturing refractories. Kaolin, bentonite, and fire clay accounted for 57%, 26%, and 13%, respectively, of total clay used for this purpose. (See table 21.) The remainder, ball clay and common clay and shale, was used chiefly as bonding agents. Bentonite, both swelling and nonswelling, was used as a bonding agent in proprietary foundry formulations imparting both hot and green strength to the sand.

The tonnage of clays used for refractories increased 6% and constituted 7% of total clay produced. The continued use of high-alumina, clay-based refractories, mostly calcined kaolin grogs in monoliths, and the upturn in demand for the more conventional refractory bricks and shapes were largely responsible. (See table 25.) The major

refractory consuming industries—cement, foundry, glass, and ferrous and nonferrous metals—continued to undergo major changes in technology and production levels for their products.

Filler.—Bentonite, fuller's earth, and kaolin are the principal filler clays. Kaolin, either air-floated, water washed, low-temperature calcined, and/or delaminated, was used in the manufacture of adhesives, paint, paper, plastics, and rubber. Fuller's earth was used primarily in pesticides and fertilizers. Clays were used in pesticides and fertilizers as either thickeners, carriers, dilutents, or prilling agents. Bentonites were used mainly in animal feeds.

Of the total clay produced, 12% was used in filler applications; of this, kaolin accounted for 86%; fuller's earth, 7%; bentonite, 3%; and ball clay, common clay and shale, and fire clay, 4%. Kaolin consumed as fillers decreased 14% to 4.4 million tons. Use of paper-coating-grade kaolin increased 4%, and the use of paper-filler-grade kaolin decreased 22%. These two categories accounted for 71% of the total filler and extender category. (See table 21.)

Absorbent Uses.—Absorbent uses for clays accounted for about 2.4 million tons or 5% of total clay consumption. Demand for absorbents increased 14%. Fuller's earth was the principal clay used for absorbent purposes. This application accounted for 88% of its entire output. Demand for clays in pet waste absorbents increased significantly. The use of fuller's earth in floor or oil and grease absorbents, chiefly to absorb hazardous oily substances, accounted for 16% of the absorbent demand. (See table 21.)

Drilling Mud.—Demand for clays in rotary-drilling muds decreased to about 724,000 tons and accounted for 2% of total clay production. Swelling-type bentonite remained the principal clay used in drilling mud mixes, although fuller's earth, used mostly in saltwater drilling techniques, and nonswelling sodium-activated bentonites were also used to a

limited extent. Bentonite and fuller's earth accounted for 100% of the total amount of clays used in this category. (See table 21.)

Floor and Wall Tile.—Common clay and shale, ball clay, and kaolin, in order of volume, were used in manufacturing floor, wall, and quarry tile. This end-use category accounted for 19% of the total clay production. (See table 21.)

Pelletizing Iron Ore.—Bentonite continued to be used as a binder in forming indurated iron ore pellets. Demand decreased 2% to 717,000 tons. (See table 21.)

Ceramics and Glass.—Total demand for clay in the manufacture of pottery, sanitaryware, china and dinnerware, and related products (excluding clay flower pots) accounted for 3% of the total clay output. This demand, principally ball and kaolin clays, decreased 28% to 1.01 million tons. The downturn in new residential housing construction, large consumers of whiteware and sanitaryware, was partially offset by the strong demand for these products in the remodeling areas. (See table 21.)

World Review

Capacity.—The data in tables 28, 29, and 30 are rated capacity for mines as of December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced on a normally sustainable long-term operating rate based on physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

Mine capacity for domestic clay production was aggregated from data voluntarily supplied by producers. The rated capacity data for the foreign mines were estimated from previous years'

production in cooperation with the Division of International Minerals. (See tables 31, 32, and 33.)

Czechoslovakia.—Czechoslovakia produces bentonite and kaolin. Bentonite is produced primarily from North and West Bohemia. Bentonite is used in metallurgical, oil drilling, and paint applications. Czechoslovakia is the sixth largest producer of kaolin. Five grades of kaolin are produced: chinaware or porcelain grade, ceramics grade, paper grade, titaniferous grade, and feldspathic grade.¹⁸

Egypt.—A kaolin deposit with estimated reserves of 30 million tons has been discovered in the Kalbafha district by the Geological Survey and Minerals Projects Authority.¹⁹

Finland.—Engelhard Corp. announced plans to construct a plant for blending imported kaolin near Kotka. The plant will be able to provide papermakers with 40,000 tons of hydrated calcined kaolin per year.²⁰

France.—Coframines acquired a majority shareholding in Kaolins d'Arvor. Kaolins d'Arvor operates a mine and processing plant near Lorient. The company produces kaolin for paper and ceramics applications. Production capacity is 32,000 tons per year.²¹

Societe Kaoliniere Armoricaine (SOKA) mines kaolin from a deposit near Quessoy. The deposit consists of two kaolin layers, a white layer and a grey layer containing 0.2% organics. A mixture of 20% white kaolin and 80% grey kaolin is used for ceramic applications. The kaolin is washed and sized using hydrocyclones. The slurry is thickened and dried to about 30% moisture content. Driers reduce the final water content to about 12%. Besides ceramics applications, the company also produces kaolin for adhesive, animal feed, fertilizer, insecticide, and rubber applications.²²

Germany.—The Fuchs-Ton Division of Watts, Blake, Bearne & Co. PLC acquired a major share in the clay operations of Didier-Werke AG. The acquisition is expected to increase the company's clay sales by one-third. The clays are sold to the wall tile, floor tile, refractory, pipe, brick, and tableware industries.²³

Redland PLC, through its German subsidiary Braas, began negotiations for the purchase of brickworks and clay reserves in eastern Germany. The company will build a clay tile plant to supply the growing roof tile market.²⁴

Spain.—Spain currently produces attapulgite, ball clay, bentonite, kaolin, and sepiolite. Attapulgite and sepiolite are mined by nine companies. Attapulgite is sold primarily for animal feed and salt water drilling applications. Some of the major applications for sepiolite are pet litter, animal feed products, catalysts, absorbents, fertilizers, and fillers. There is only one major producer of bentonite, Minas de Gador SA. The company mines calcium bentonite in Almeria and Madrid. Untreated, ion-exchanged, and acid activated bentonites are produced for foundry applications, vegetable oil bleaching, animal feed, ceramic, and wine clarification. Ball clay is produced by SA Minera Catalono-Aragonesa for applications such as stoneware, bricks, and roof tiles. Kaolin is produced by six companies, primarily for paper, glass, and ceramic applications.²⁵

United Kingdom.—Laporte PLC announced plans to construct a clay processing facility in Cheshire. The plant capacity will be 200,000 tons per year of activated earth-based material and absorbent granules.²⁶

Current Research

The U.S. Bureau of Mines completed a study of the bonding mechanism between montmorillonite and high molecular weight polymers using infrared spectrophotometry. High molecular

weight polymers such as polyacrylamide (PAM) and polyethylene oxide (PEO) are used as flocculating agents. The results suggested that PAM was adsorbed to the clay by nitrogen atom of the polymer. PEO was bonded to the clay through a water bridge. PEO was thought to be adsorbed directly onto the surface of the bentonite.²⁷

OUTLOOK

U.S. clay demand between 1982 and 1992 has rebounded slowly from 32 million to 44 million tons. This is well below the levels of the early 1970's. In general, there has been a decrease in construction activity in the public, private, and commercial sectors. Higher mortgage rates in the late 1970's and early 1980's and the limited availability of affordable housing and funds for public and business ventures contributed to the problem. The slow economy of recent years continued to depress construction activities despite declining interest rates. Demand for common clay and shale, which are strongly tied to the construction industry, has declined over the past 10 years. Kaolin, ball clay, and fuller's earth have fared better than their common clay and shale counterparts because they are used in more diversified applications and industries. Domestic demand for specialty clays should remain strong in the near future.

The weak U.S. dollar in the latter part of the decade encouraged specialty clays producers to expand their share of export markets. Exports of domestic clays, mostly kaolin, bentonite, ball clay, and fuller's earth, are restricted to the higher valued specially treated varieties for use in drilling muds, papercoating, and iron ore pelletizing and by the foundry industry. Export markets should continue to remain strong in the near future. Imports of clays, except for English china and ball clays and acid-activated bentonites, are minor. The English clays enjoy a small prestige-dictated market, while the activated clays are confined to use in the Southern and Northern States.

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TABLE 1
SALIENT U.S. CLAYS AND CLAY PRODUCTS STATISTICS¹

(Thousand metric tons and thousand dollars)

	1987	1988	1989	1990	1991
Domestic clays sold or used by producers:					
Quantity	43,234	44,515	42,254	42,904	44,092
Value	\$1,202,284	\$1,390,908	\$1,515,300	\$1,619,824	\$1,505,423
Exports:					
Quantity	3,023	3,535	3,755	4,123	3,997
Value	\$512,964	\$516,566	\$550,343	\$584,404	\$590,174
Imports for consumption:					
Quantity	34	33	28	30	35
Value	\$9,392	\$8,835	\$10,928	\$11,988	\$13,249
Clay refractories shipments: Value	\$739,770	\$813,739	\$823,266	\$802,530	NA
Clay construction products shipments: Value	\$1,782,023	\$1,927,000	\$1,786,000	\$1,775,000	\$1,418,000

¹Revised. NA Not available.

²Excludes Puerto Rico.

TABLE 2
CLAYS SOLD OR USED BY PRODUCERS IN THE UNITED STATES¹ IN 1991, BY STATE

(Thousand metric tons and thousand dollars)

State	Ball clay	Bentonite	Common clay and shale	Fire clay	Fuller's earth	Kaolin	Total ²	Total value
Alabama	—	W	2,044	81	—	W	³ 2,124	³ 22,104
Arizona	—	35	193	—	—	—	228	3,830
Arkansas	—	—	645	W	—	212	⁵ 857	⁵ 8,048
California	—	147	1,815	—	W	113	⁶ 2,075	⁶ 27,463
Colorado	—	W	261	3	—	—	² 264	¹ 1,964
Connecticut	—	—	W	—	—	—	W	W
Florida	—	—	W	—	332	31	³ 363	³ 39,150
Georgia	—	—	1,382	—	617	7,519	9,518	949,737
Idaho	—	—	W	—	—	1	¹ 1	W
Illinois	—	—	514	—	421	—	935	38,877
Indiana	W	—	930	—	—	—	⁹ 930	⁹ 3,516
Iowa	—	—	530	—	—	—	530	2,226
Kansas	—	—	607	—	—	—	607	2,828
Kentucky	W	—	708	—	—	—	⁷ 708	² 9,942
Louisiana	—	—	360	—	—	—	360	3,646
Maine	—	—	W	—	—	—	W	W
Maryland	—	—	259	—	—	—	259	1,141
Massachusetts	—	—	W	—	—	—	W	W
Michigan	—	—	2,062	—	—	—	2,062	8,770
Minnesota	—	—	W	—	—	W	W	W
Mississippi	W	211	648	—	313	W	⁴ 1,172	⁴ 34,382
Missouri	—	—	1,751	251	W	—	² 2,002	⁶ 11,059
Montana	—	320	42	—	—	—	363	11,332
Nebraska	—	—	198	—	—	—	198	909
Nevada	—	16	—	—	W	W	⁴ 16	⁴ 3,204
New Hampshire	—	—	W	—	—	—	W	W
New Jersey	—	—	W	W	—	—	W	W
New Mexico	—	—	28	W	—	—	² 28	⁷ 74
New York	—	—	421	—	—	—	421	2,417
North Carolina	—	—	2,064	—	—	W	² 2,064	⁹ 9,015
North Dakota	—	—	28	—	—	—	28	W
Ohio	—	—	2,116	89	—	—	2,205	11,016
Oklahoma	—	—	824	—	—	—	824	4,178
Oregon	—	19	194	—	—	—	213	1,086
Pennsylvania	—	—	701	W	—	W	⁴ 701	⁴ 2,890
Puerto Rico	—	—	145	—	—	—	145	335
South Carolina	—	—	1,154	—	—	555	1,709	25,663
South Dakota	—	—	W	—	—	—	W	W
Tennessee	514	—	W	—	314	W	⁴ 7829	⁴ 744,573
Texas	W	W	2,266	—	W	W	^{3 4 6} 2,266	^{3 4 6} 13,247
Utah	—	W	210	—	—	—	² 210	¹ 1,028
Virginia	—	—	723	—	W	—	⁶ 723	³ 3,248
Washington	—	—	263	—	—	—	263	2,633
West Virginia	—	—	134	—	—	—	134	322

See footnotes at end of table.

TABLE 2—Continued
CLAYS SOLD OR USED BY PRODUCERS IN THE UNITED STATES¹ IN 1991, BY STATE

(Thousand metric tons and thousand dollars)

State	Ball clay	Bentonite	Common clay and shale	Fire clay	Fuller's earth	Kaolin	Total ²	Total value
Wyoming	—	2,496	W	—	—	—	² 2,496	³ 81,573
Undistributed	270	187	1,010	51	743	1,144	3,404	124,996
Total ²	784	3,432	27,233	474	2,740	9,575	44,237	1,505,423

W Withheld to avoid disclosing company proprietary data; included with "Total" and/or "Undistributed."

¹Includes Puerto Rico.

²Data may not add to totals shown because of independent rounding.

³Excludes bentonite.

⁴Excludes kaolin.

⁵Excludes fire clay.

⁶Excludes fuller's earth.

⁷Excludes common clay.

⁸Excludes ball clay.

TABLE 3
**NUMBER OF MINES FROM WHICH PRODUCERS SOLD OR USED
 CLAYS IN THE UNITED STATES¹ ² IN 1991, BY STATE**

State	Ball clay	Ben- tonite	Common clay and shale	Fire clay	Fuller's earth	Kaolin	Total
Alabama	—	1	28	5	—	19	53
Arizona	—	3	6	—	—	—	9
Arkansas	—	—	18	2	—	3	23
California	1	7	39	—	2	4	53
Colorado	—	1	27	3	—	—	31
Connecticut	—	—	2	—	—	—	2
Florida	—	—	3	—	5	1	9
Georgia	—	—	14	—	9	73	96
Idaho	—	1	1	—	—	2	4
Illinois	—	—	9	—	4	—	13
Indiana	1	—	13	—	—	1	15
Iowa	—	—	12	—	—	—	12
Kansas	—	1	23	—	—	—	24
Kentucky	7	—	14	1	—	—	22
Louisiana	—	—	8	—	—	—	8
Maine	—	—	3	—	—	—	3
Maryland	—	—	7	—	—	—	7
Massachusetts	—	—	2	—	—	—	2
Michigan	—	—	8	—	—	—	8
Minnesota	—	—	1	—	—	2	3
Mississippi	1	3	16	—	3	—	23
Missouri	—	1	11	44	4	—	60
Montana	—	5	6	1	—	—	12
Nebraska	—	—	5	—	—	—	5
Nevada	—	8	—	—	2	2	12
New Hampshire	—	—	1	—	—	—	1
New Jersey	—	—	1	1	—	—	2
New Mexico	—	—	4	2	—	—	6
New York	—	—	9	—	—	—	9
North Carolina	—	—	46	—	—	2	48
North Dakota	—	—	3	—	—	—	3
Ohio	—	—	49	6	—	—	55
Oklahoma	—	—	21	—	—	—	21
Oregon	—	11	7	—	—	—	18
Pennsylvania	—	—	29	4	—	1	34
Puerto Rico	—	—	2	—	—	—	2
South Carolina	—	—	30	—	1	17	48
South Dakota	—	—	1	—	—	—	1
Tennessee	23	—	6	—	5	—	34
Texas	3	10	67	3	1	1	85
Utah	—	3	13	—	—	—	16
Virginia	—	—	14	—	1	—	15
Washington	—	—	10	6	—	—	16
West Virginia	—	—	3	—	—	—	3
Wyoming	—	89	3	—	—	—	92
Total	36	144	595	78	37	128	1,018

¹Includes both active and idle operations.

²Includes Puerto Rico.

TABLE 4
KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES,
BY STATE

(Thousand metric tons and thousand dollars)

State	1990		1991	
	Quantity	Value	Quantity	Value
Arkansas	284	18,779	212	5,416
California	122	4,995	113	4,865
Florida	38	W	31	3,552
Georgia	7,043	862,295	7,519	862,866
South Carolina	1,231	42,409	555	23,437
Other ¹	425	25,388	1,145	21,758
Total	9,143	953,866	9,575	921,894

¹Revised. W Withheld to avoid disclosing company proprietary data; included in "Other."

²Includes Alabama, Idaho, Minnesota, Mississippi, Nevada, North Carolina, Pennsylvania, Tennessee, and Texas.

TABLE 5
KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY KIND

(Thousand metric tons and thousand dollars)

Kind	1990		1991	
	Quantity	Value	Quantity	Value
Airfloat	1,451	84,576	1,142	63,654
Calcined ¹	1,385	287,792	2,444	290,990
Delaminated	1,221	148,420	996	110,997
Unprocessed	1,246	17,337	807	12,483
Water-washed	3,840	415,740	4,186	443,769
Total²	9,143	953,866	9,575	921,894

¹Revised.

²Includes both low-temperature filler and high-temperature refractory grades.

³Data may not add to totals shown because of independent rounding.

TABLE 6
CALCINED KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	High-temperature		Low-temperature	
	Quantity	Value	Quantity	Value
1990				
Alabama and Georgia	553	70,362	¹ 473	¹ 188,109
Other	² 208	² 17,400	³ 152	³ 11,921
Total	²761	²87,762	³625	³200,030
1991				
Alabama and Georgia	1,509	32,417	¹ 718	¹ 245,240
Other	² 110	² 4,292	³ 107	³ 9,041
Total	1,619	36,709	825	254,281

¹Revised.

²Excludes Alabama.

³Includes Arkansas, California, Colorado, Idaho, and South Carolina.

⁴Includes Arkansas, Pennsylvania, and South Carolina.

TABLE 7
GEORGIA KAOLIN SOLD OR USED BY PRODUCERS, BY KIND

(Thousand metric tons and thousand dollars)

Kind	1990		1991	
	Quantity	Value	Quantity	Value
Airfloat	863	40,346	702	34,790
Calcined ¹	² 975	² 252,959	1,500	269,457
Delaminated	¹ 1,221	¹ 148,420	996	110,997
Unprocessed	231	9,140	178	5,589
Water-washed	³ 3,752	³ 411,431	4,144	442,032
Total²	²7,043	²862,295	7,519	862,866

¹Revised.

²Includes both low-temperature filler and high-temperature refractory grades.

³Data may not add to totals shown because of independent rounding.

TABLE 8
GEORGIA KAOLIN SOLD OR USED BY PRODUCERS, BY USE

(Thousand metric tons)

Use	1990				1991			
	Air-float	Unpro-cessed ¹	Water-washed ²	Total ³	Air-float	Unpro-cessed ¹	Water-washed ²	Total ³
Domestic:								
Adhesives	21	—	21	42	W	—	26	26
Aluminum sulfate and other chemicals	—	W	—	W	—	W	—	W
Asphalt tile and linoleum	W	W	—	W	W	W	—	W
Catalysts (oil-refining)	W	—	38	38	W	—	35	35
Face brick	—	9	—	9	—	4	—	4
Fiberglass and mineral wool	199	—	W	199	223	—	W	223
Fine china and dinnerware; crockery and earthenware	10	—	—	10	W	—	W	W
Firebrick, blocks and shapes	W	7	—	7	W	9	—	9
Grogs and calcines, refractory	W	W	W	W	W	W	W	W
Medical, pharmaceutical, cosmetic	W	—	W	W	W	—	W	W
Paint	19	—	207	226	W	—	200	200
Paper coating	W	—	2,442	2,442	—	—	2,604	2,604
Paper filling	147	—	1,192	1,339	147	—	905	1,052
Plastics	14	—	32	47	W	—	50	50
Pottery	25	—	—	25	W	—	—	W
Refractories ⁴	15	W	7	22	7	23	8	38
Roofing granules	W	W	—	W	W	W	—	W
Rubber	13	—	46	59	14	—	40	55
Sanitaryware	39	—	—	39	33	—	—	33
Miscellaneous, airfloat:								
Common brick, fertilizers, gypsum products, pesticides and related products, roofing and structural tile, other uses not specified	271	—	—	271	247	—	—	247
Miscellaneous, unprocessed:								
Fertilizers, pesticides and related products, other uses not specified	—	718	—	718	—	879	—	879
Miscellaneous, water-washed:								
Gypsum products, ink, pesticides and related products, waterproofing and sealing, fertilizers, other uses not specified	—	—	199	199	—	—	185	185
Total⁵	774	733	4,184	5,692	671	915	4,053	5,639
Exports:								
Paint	—	—	26	26	—	—	W	W
Paper coating	W	—	971	971	—	W	1,321	1,321
Paper filling	38	—	191	229	—	—	386	386
Rubber	—	—	W	W	—	—	16	16
Undistributed	51	(⁶)	73	124	30	44	83	157
Total⁵	89	(⁶)	1,262	1,351	30	44	1,805	1,880
Grand total⁵	863	734	5,446	7,043	702	959	5,858	7,519

¹Revised. W Withheld to avoid disclosing company proprietary data; included in "Undistributed."

²Includes high-temperature calcined.

³Includes low-temperature calcined and delaminated.

⁴Data may not add to totals shown because of independent rounding.

⁵Includes electrical porcelain; floor and wall tile, ceramic; flue linings; glazes, glass, and enamels; high-alumina brick and specialties; kiln furniture; refractory mortar and cement.

⁶Less than 1/2 unit.

TABLE 9
SOUTH CAROLINA KAOLIN SOLD OR USED BY PRODUCERS,
BY KIND

(Thousand metric tons and thousand dollars)

Kind	1990		1991	
	Quantity	Value	Quantity	Value
Airfloat	497	37,372	352	21,765
Unprocessed	734	5,036	203	1,672
Total	1,231	42,000	555	23,437

¹Revised.

¹Data do not add to total shown because of independent rounding.

TABLE 10
SOUTH CAROLINA KAOLIN SOLD OR USED BY PRODUCERS,
BY KIND AND USE

(Thousand metric tons)

Kind and use	1990	1991
Airfloat:		
Adhesives	12	W
Animal feed and pet waste absorbent	W	W
Ceramics ¹	6	3
Fertilizers, pesticides and related products	19	8
Fiberglass	135	W
Paint	W	W
Paper coating and filling	17	4
Plastics	W	W
Rubber	148	167
Refractories ²	7	W
Other uses ³	92	144
Exports ⁴	60	29
Total	497	353
Unprocessed: Face brick and other uses	734	203
Grand total	1,231	555

¹Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Includes crockery and earthenware; electrical porcelain; fine china and dinnerware; floor and wall tile; pottery; and roofing granules.

²Includes refractory calcines and grogs; firebrick, blocks and shapes; refractory mortar and cement; and high-alumina refractories.

³Includes animal oil; catalysts (oil refining); chemical manufacturing; ink; medical; sewer pipe; and unknown uses.

⁴Includes ceramics; adhesives; paper filling; pesticides and related products; and rubber.

⁵Data do not add to total shown because of independent rounding.

TABLE 11
KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Thousand metric tons)

Use	1990				1991			
	Air- float	Unpro- cessed ¹	Water- washed ²	Total ³	Air- float	Unpro- cessed ¹	Water- washed ²	Total ³
Domestic:								
Adhesives	33	—	22	55	27	—	26	52
Aluminum sulfate and other chemicals	—	136	72	208	—	W	W	170
Animal feed	W	—	W	W	W	—	—	W
Brick, extruded and other	W	220	W	291	—	231	W	231
Catalysts (oil and gas refining)	51	—	40	91	W	—	38	38
Cement, portland	—	176	—	176	—	180	—	180
China and dinnerware	18	—	—	18	15	—	W	15
Crockery and other earthenware	3	—	—	3	1	—	W	1
Electrical porcelain	14	—	2	16	6	—	3	9
Fertilizers ⁴	W	—	W	3	W	—	W	5
Fiberglass, mineral wool and other insulation	369	—	85	454	328	W	W	400
Firebrick, blocks and shapes	63	67	5	135	67	59	—	126
Floor and wall tile, ceramic; glazes, glass, enamels	W	W	W	W	W	W	W	W
Flue linings, high-alumina brick and specialties	W	W	W	W	W	W	W	W
Foundry sand	W	W	W	1	—	—	W	W
Grogs and calcines, refractory	W	756	W	759	W	1,633	W	1,633
Gypsum products and wallboard	W	W	W	W	W	W	W	3
Ink	—	—	W	W	—	—	7	7
Kiln furniture; refractory mortar and cement	W	—	W	W	W	—	—	W
Linoleum and asphalt tile	W	—	W	W	W	—	W	W
Medical, pharmaceutical, cosmetic	3	—	(⁵)	3	W	—	W	1
Paint	20	3	238	261	3	W	225	228
Paper coating	54	—	2,442	2,496	W	—	2,604	2,604
Paper filling	164	—	1,193	1,358	152	—	905	1,057
Pesticides and related products	19	—	31	50	7	—	16	23
Plastics	21	—	32	54	5	—	50	55
Pottery	28	—	—	28	22	—	—	22
Roofing granules	W	W	—	10	W	W	—	11
Rubber	161	1	46	208	181	W	40	221
Sanitaryware	41	—	—	41	35	—	—	35
Waterproofing and sealing	—	—	W	W	W	—	W	W
Miscellaneous	222	647	214	997	219	272	288	516
Total³	1,284	2,006	4,423	7,713	1,068	2,374	4,201	7,643
Exports:								
Ceramics	42	—	W	42	44	—	47	91
Foundry sand, grogs and calcines; other refractories	—	—	—	—	—	6	—	6
Paint	—	—	26	26	—	—	W	W
Paper coating	W	—	971	971	—	W	1,321	1,321
Paper filling	39	—	191	230	—	—	386	386
Rubber	60	—	W	60	29	—	16	45
Miscellaneous	26	(⁵)	75	102	1	44	37	83
Total³	167	(⁵)	1,263	1,430	74	51	1,807	1,931
Grand total³	1,451	2,007	5,686	9,143	1,142	2,425	6,008	9,575

¹Revised. W Withheld to avoid disclosing proprietary data; included with "Total" and/or "Miscellaneous."

²Includes high-temperature calcined.

³Includes low-temperature calcined and delaminated.

⁴Data may not add to totals shown because of independent rounding.

⁵Includes soil conditioners and mulches.

⁶Less than 1/2 unit.

**TABLE 12
PRICE QUOTATIONS FOR KAOLIN AND BALL CLAY, 1991**

	Per metric ton
Kaolin:	
Water-washed, fully calcined bags, carload lots, f.o.b. Georgia per ton	323.00
Calcined, paper-grade, same basis, per ton	470.00
Paper-grade, uncalcined, bulk, carload lots, f.o.b. Georgia, per ton:	
No. 1 coating	110.00
No. 2 coating	87.00
No. 3 coating	85.00
No. 4 coating	82.00
Filler, general purpose, same basis per ton	64.00
Delaminated, water-washed, uncalcined, painted-grade, 1-micrometer average, same basis, per ton	284.00
Dry-ground, airfloated, soft, same basis per ton	52.00
National Formulary, powder, colloidal, bacteria controlled, 50-pound bags, 5,000-pound lots, per ton	273.00
Ball clay:	
Domestic, airfloated, bags, carload lots Tennessee, per ton	49.00
Domestic, crushed, moisture-repellent, bulk carload lots, Tennessee, per ton	24.00

Source: Chemical Marketing Reporter, v. 240, No. 26, Jan. 6, 1992, pp. 26-36.

**TABLE 13
BALL CLAY SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE**

(Thousand metric tons and thousand dollars)

State	Airfloat		Water-slurried		Unprocessed		Total	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1990								
Tennessee	261	12,904	130	5,476	153	4,291	544	22,671
Other ¹	160	8,106	—	—	84	2,679	244	10,786
Total²	421	21,010	130	5,476	236	6,970	788	33,456
1991								
Tennessee	231	11,597	129	5,610	154	4,418	514	21,625
Other ¹	128	6,887	—	—	141	4,909	270	11,796
Total²	360	18,483	129	5,610	295	9,327	784	33,421

¹Includes Indiana, Kentucky, Mississippi, and Texas.

²Data may not add to totals shown because of independent rounding.

TABLE 14
BALL CLAY SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Thousand metric tons)

Use	1990				1991			
	Airfloat	Water-slurried	Unprocessed	Total	Airfloat	Water-slurried	Unprocessed	Total
Ceramics ¹	W	—	W	12	W	—	W	9
Dinnerware ²	100	—	W	100	89	—	28	117
Fillers, extenders, and binders ³	101	—	1	103	102	—	18	120
Floor and wall tile	35	12	112	158	16	W	132	148
Refractories ⁴	39	W	1	40	32	W	6	38
Sanitaryware	W	107	52	158	W	110	45	155
Miscellaneous	72	W	54	127	54	19	43	107
Exports	74	—	17	91	67	—	23	90
Total⁵	421	130	236	788	360	129	295	784

W Withheld to avoid disclosing company proprietary data; included in "Total" and/or "Miscellaneous."

¹Includes catalyst (oil refining); fiberglass; glazes, glass, and enamels.

²Includes crockery and other earthenware; fine china and dinnerware.

³Includes animal food; asphalt emulsions, asphalt tile; pesticides and related products; rubber; wallboard, other uses not specified.

⁴Includes electrical porcelain; firebrick, block and shapes; high-alumina brick and specialties.

⁵Data may not add to totals shown because of independent rounding.

TABLE 15
FIRE CLAY¹ SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1990		1991	
	Quantity	Value	Quantity	Value
Alabama	96	3,981	81	3,494
Colorado	—	—	3	26
Missouri	283	7,652	251	5,476
New Jersey	W	W	W	W
New Mexico	W	W	W	W
Ohio	226	4,038	89	2,844
Pennsylvania	W	W	—	—
Other	21	458	51	1,338
Total²	626	16,128	474	13,178

W Withheld to avoid disclosing company proprietary data; included in "Other."

¹Refractory uses only.

²Data may not add to totals shown because of independent rounding.

TABLE 16
BENTONITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	Nonswelling		Swelling		Total	
	Quantity	Value	Quantity	Value	Quantity	Value
1990						
Alabama and Mississippi	411	17,217	—	—	411	17,217
Arizona	38	W	(¹)	W	38	W
California	136	11,403	17	1,618	153	13,021
Colorado	—	—	(¹)	4	(¹)	4
Nevada	W	W	W	W	35	4,098
Oregon	—	—	25	1,063	25	1,063
Utah	W	W	W	W	W	W
Wyoming	—	—	2,524	76,083	2,524	76,083
Other ²	47	2,954	276	12,648	288	11,505
Total³	632	31,575	2,842	91,417	3,474	122,991
1991						
Alabama and Mississippi	281	9,337	W	W	281	9,337
Arizona	17	1,378	W	W	17	1,378
California	129	11,176	W	W	129	11,176
Colorado	W	7	—	—	W	7
Nevada	W	W	W	W	16	3,204
Oregon	W	W	W	W	19	786
Utah	W	40	W	1,104	W	1,144
Wyoming	—	—	2,496	81,573	2,496	81,573
Other ²	47	1,031	461	19,744	473	16,784
Total³	475	22,969	2,957	102,420	3,432	125,389

¹Revised. W Withheld to avoid disclosing company proprietary data; included in "Other."

²Less than 1/2 unit.

³Includes Montana and Texas.

⁴Data may not add to totals shown because of independent rounding.

TABLE 17
BENTONITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Thousand metric tons)

Use	1990			1991		
	Non-swelling	Swelling	Total ¹	Non-swelling	Swelling	Total ¹
Domestic:						
Absorbents	W	W	W	129	175	305
Adhesives	—	4	4	—	11	11
Animal feed	15	91	106	9	91	100
Catalysts (oil-refining)	W	—	W	W	—	W
Drilling mud	2	711	713	1	691	693
Filtering, clarifying, decolorizing:						
Animal oils, mineral oils and greases, and vegetable oils	30	35	65	W	W	5
Desiccants	W	—	W	W	—	W
Foundry sand	226	638	865	W	585	585
Medical, pharmaceutical, cosmetic	W	16	16	W	W	W
Paint	—	6	6	—	15	15
Pelletizing (iron ore)	—	683	683	—	717	717
Pesticides and related products	W	W	W	W	W	W
Water treatment and filtering	W	W	W	W	W	W
Waterproofing and sealing	15	141	156	83	133	216
Miscellaneous ²	304	94	398	4	107	351
Total¹	591	2,420	3,011	468	2,526	2,993
Exports:						
Drilling mud	—	113	113	—	107	107
Foundry sand	2	252	254	W	272	272
Other ³	38	57	95	W	53	60
Total¹	41	422	462	7	431	438
Grand total¹	632	2,842	3,474	475	2,957	3,432

W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous."

¹Data may not add to totals shown because of independent rounding.

²Includes data for asphalt emulsions; asphalt tile; cement, portland; ceramic floor and wall tile; face brick; fertilizers; firebrick, blocks and shapes; gypsum products; ink; kiln furniture; mineral wool and insulation; oil well sealing; paper coating and filling; plastics; pottery; roofing tile; rubber; uses not specified; and data indicated by symbol W.

³Includes absorbents; animal feed; asphalt emulsions; cement; filtering, clarifying, decolorizing; paint; plastics; waterproofing and sealing; and uses not specified.

TABLE 18
FULLER'S EARTH SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	Attapulgite		Montmorillonite		Total	
	Quantity	Value	Quantity	Value	Quantity	Value
1990						
Florida	353	35,928	(¹)	(¹)	353	35,928
Georgia	461	59,243	187	13,487	648	72,729
Southern States ²	—	—	509	33,970	509	33,970
Western States ³	(¹)	(¹)	798	81,018	798	81,018
Total⁵	745	95,171	1,563	128,475	2,307	223,645
1991						
Florida	332	35,598	(¹)	(¹)	332	35,598
Georgia	509	63,273	108	13,134	617	76,407
Southern States ²	—	—	677	49,648	677	49,648
Western States ³	(¹)	(¹)	1,114	108,782	1,114	108,782
Total⁵	758	98,871	1,982	171,564	2,740	270,435

¹Included under attapulgite.

²Includes Mississippi, Tennessee, and Virginia.

³Includes California, Illinois, Missouri, Nevada, and Texas.

⁴Included under montmorillonite.

⁵Data may not add to totals shown because of independent rounding.

TABLE 19
FULLER'S EARTH SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Thousand metric tons)

Use	1990			1991		
	Attapulgite	Montmorillonite	Total ¹	Attapulgite	Montmorillonite	Total ¹
Domestic:						
Adhesives	W	—	W	W	—	W
Drilling mud	34	—	34	32	—	32
Fertilizers	44	W	44	39	W	39
Filtering, clarifying, decolorizing mineral oils and greases	13	—	13	20	W	20
Medical, pharmaceutical, cosmetic	W	—	W	W	—	W
Oil and grease absorbents	151	219	370	167	180	348
Paint	W	—	W	W	—	W
Pesticides and related products	85	83	168	57	142	199
Pet waste absorbents	220	1,128	1,347	224	1,549	1,773
Portland and other cement	—	W	W	26	—	26
Other ²	W	—	W	W	—	W
Miscellaneous ³	105	86	192	113	60	174
Exports:	94	46	140	79	49	129
Grand total¹	745	1,563	2,307	758	1,982	2,740

W Withheld to avoid disclosing company proprietary data; included with "Other" and/or "Miscellaneous."

¹Data may not add to totals shown because of independent rounding.

²Includes roofing tile and vegetable oils.

³Includes animal feed; animal oils; gypsum products; miscellaneous absorbents; miscellaneous fillers, extenders, and binders; miscellaneous filtering, clarifying; mortar and cement refractories; plastics; roofing tiles; wallboard; water treatment and filtering; waterproofing and sealing; and other uses not specified.

TABLE 20
COMMON CLAY AND SHALE SOLD OR USED BY PRODUCERS IN THE UNITED STATES,¹ BY STATE

(Thousand metric tons and thousand dollars)

State	1990		1991	
	Quantity	Value	Quantity	Value
Alabama	1,954	16,266	2,044	18,609
Arizona	103	470	193	937
Arkansas	705	2,799	645	2,632
California	1,699	14,206	1,815	9,714
Colorado	262	1,864	261	1,938
Connecticut and New Jersey	165	2,294	147	1,899
Georgia	1,546	7,015	1,382	10,464
Illinois	598	2,516	514	2,442
Indiana	1,052	3,273	930	3,516
Iowa	423	1,376	530	2,226
Kansas	626	4,056	607	2,828
Kentucky	826	8,282	708	2,942
Louisiana	368	1,066	360	3,646
Maine and Massachusetts	52	237	59	264
Maryland	339	1,712	259	1,141
Michigan	1,202	4,094	2,062	8,770
Mississippi	528	2,568	648	6,608
Missouri	1,065	5,212	1,751	5,584
Montana	30	193	42	167
Nebraska	227	1,685	198	909
New Mexico	28	74	28	74
New York	491	2,906	421	2,417
North Carolina	2,179	9,356	2,064	9,015
Ohio	2,320	9,296	2,116	8,171
Oklahoma	631	3,156	824	4,178
Oregon	199	327	194	300
Pennsylvania	841	2,900	701	2,890
Puerto Rico	148	W	145	335
South Carolina	832	2,077	1,154	2,225
South Dakota and Wyoming	163	776	224	939
Tennessee	482	W	W	W
Texas	2,106	13,058	2,266	13,247
Utah	278	1,774	210	1,028
Virginia	882	3,741	723	3,248
Washington	158	1,357	263	2,633
West Virginia	164	384	134	322
Other ²	233	3,969	608	2,846
Total ³	25,906	136,333	27,233	141,106

¹Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."

²Includes Puerto Rico.

³Includes Florida, Idaho, Minnesota, New Hampshire, and North Dakota.

⁴Data may not add to totals shown because of independent rounding.

TABLE 21
CLAYS SOLD OR USED BY PRODUCERS IN THE UNITED STATES¹ IN 1991, BY USE

(Thousand metric tons)

Use	Ball clay	Bentonite	Common clay and shale	Fire clay (refractory only)	Fuller's earth	Kaolin	Total
Absorbents:							
Oil and grease	—	81	—	—	315	—	395
Pet waste absorbents	—	217	—	—	1,773	—	1,991
Other ²	W	W	—	—	33	—	33
Ceramics and glass:							
Catalysts (oil-refining)	—	W	—	—	W	38	38
Crockery and other earthenware	—	—	W	—	—	1	1
Electrical porcelain	19	—	—	—	W	9	28
Fine china and dinnerware	2	—	—	—	—	15	18
Glazes, glass and enamels	—	W	—	W	—	W	W
Mineral wool and insulation, fiberglass	—	W	—	—	—	400	400
Pottery	115	W	35	W	—	22	171
Roofing granules	—	—	W	—	W	11	11
Sanitaryware	155	—	—	—	—	35	190
Other ²	11	32	217	21	15	174	471
Chemical manufacturing	—	—	—	W	W	170	170
Civil engineering and sealing	12	177	84	—	—	44	317
Drilling mud	—	693	—	—	32	—	724
Fillers, extenders and binders:							
Adhesives	W	11	—	—	W	52	64
Animal feed	W	100	—	—	37	W	137
Fertilizers	—	W	—	—	39	5	45
Gypsum products and wallboard	W	—	—	—	W	3	3
Ink	—	W	—	—	—	7	7
Medical, pharmaceutical, cosmetic	—	W	—	—	W	1	1
Paint	W	15	W	—	W	228	243
Paper coating	—	W	—	—	—	2,604	2,604
Paper filling	W	—	—	—	W	1,057	1,057
Pesticides and related products	W	W	—	—	199	23	222
Plastics	W	W	—	—	W	55	55
Rubber	W	W	—	—	W	221	221
Other ²	135	15	80	—	94	159	482
Filtering, clarifying, decolorizing:							
Animal oils, mineral oils and greases, and vegetable oils	—	5	—	—	20	—	26
Desiccants	—	W	—	—	—	—	W
Floor and wall tile:							
Ceramic	158	(³)	279	—	—	W	437
Quarry tile	10	—	50	—	—	—	60
Other ²	—	—	W	—	—	W	W
Heavy clay products:							
Brick, extruded	W	W	9,120	—	—	245	9,365
Brick, other	—	—	2,645	W	—	12	2,657
Drain tile	—	—	13	—	—	—	13
Flower pots	—	—	25	—	—	—	25
Flue linings	—	—	47	—	—	W	47
Portland and other cements	—	W	10,013	W	26	180	10,219

See footnotes at end of table.

TABLE 21—Continued
CLAYS SOLD OR USED BY PRODUCERS IN THE UNITED STATES¹ IN 1991, BY USE

(Thousand metric tons)

Use	Ball clay	Bentonite	Common clay and shale	Fire clay (refractory only)	Fuller's earth	Kaolin	Total
Heavy clay products—Continued:							
Roofing tile	—	W	W	—	—	—	W
Sewer pipe, vitrified	—	—	W	—	—	—	W
Structural tile	—	—	36	—	—	—	36
Other ²	W	5	688	21	—	18	732
Lightweight aggregate:							
Concrete	—	—	2,438	—	—	—	2,438
Highway surfacing	—	—	274	—	—	—	274
Structural concrete	—	—	707	—	—	—	707
Other ²	—	W	180	—	W	—	180
Pelletizing iron ore	—	717	W	—	—	—	717
Refractories:							
Firebrick, blocks, and shapes	1	W	92	319	—	126	539
Foundry sand	—	585	—	W	—	W	585
Grogs and calcines	—	—	—	W	—	1,633	1,633
High alumina brick and specialties	15	—	—	27	—	W	42
Kiln furniture	1	W	—	—	—	W	1
Mortar and cement, refractory	—	—	W	—	—	—	W
Other ²	W	243	6	66	W	31	346
Other ⁴	51	96	197	14	27	65	450
Exports	90	438	7	4	129	1,931	2,599
Total⁵	784	3,432	27,233	474	2,740	9,575	44,237

W Withheld to avoid disclosing company proprietary data; included in "Total" and/or "Other."

¹Includes Puerto Rico.

²Includes uses indicated by symbol W.

³Less than 1/2 unit.

⁴Uses not specified.

⁵Data may not add to totals shown because of independent rounding.

TABLE 22
SHIPMENTS OF PRINCIPAL STRUCTURAL CLAY PRODUCTS IN THE UNITED STATES

Product	1987	1988	1989	1990	1991
Unglazed common and face brick:					
Quantity million standard brick	7,313	7,811	6,698	6,783	5,405
Value million	\$1,060	\$1,188	\$1,000	\$1,014	\$796
Unglazed structural tile:¹					
Quantity thousand metric tons	84	53	W	W	W
Value million	\$50	\$6	W	W	W
Vitrified clay and sewer pipe fittings:					
Quantity thousand metric tons	295	286	232	220	187
Value million	\$74	\$74	\$64	\$60	\$51
Unglazed, salt-glazed, ceramic-glazed structural facing tile including glazed brick:					
Quantity million standard brick	32	26	35	31	W
Value million	\$11	\$18	\$15	\$14	W
Clay floor and wall tile including quarry tile:					
Quantity million square feet	462	488	545	509	430
Value million	\$587	\$641	\$707	\$687	\$571
Total value do.	\$1,782	\$1,927	\$1,786	\$1,775	\$1,418

W Withheld to avoid disclosing individual company proprietary data.

¹Includes first 9 months only, 1987.

Source: Bureau of the Census Report Form M32-D(92)-1, Current Industrial Reports Clay Construction Products.

TABLE 23
COMMON CLAY AND SHALE USED IN BUILDING BRICK
PRODUCTION IN THE UNITED STATES, BY STATE¹

(Thousand metric tons and thousand dollars)

State	1990		1991	
	Quantity	Value ²	Quantity	Value
Alabama	953	4,799	794	3,552
Arizona ² and New Mexico ²	60	169	65	201
Arkansas	322	835	279	707
California	400	7,640	396	1,965
Colorado	229	1,724	233	1,814
Connecticut, New Jersey, ² New York ²	352	3,097	297	2,612
Georgia	977	5,316	938	3,402
Idaho, Washington, Wyoming, ² Montana ³	97	789	97	613
Illinois	109	487	464	2,074
Indiana and Iowa	405	1,371	322	1,610
Kansas	158	586	151	547
Kentucky ² and Tennessee ²	743	8,188	635	2,933
Louisiana	83	280	75	2,852
Maine, Massachusetts, ² New Hampshire ²	63	309	62	283
Maryland and West Virginia ⁴	355	1,697	244	1,012
Michigan ² and Minnesota ²	163	456	121	422
Mississippi	374	2,407	390	2,124
Missouri	173	583	205	849
Nebraska and North Dakota ²	176	507	146	435
North Carolina	1,844	5,659	1,722	5,269
Ohio	1,055	5,202	949	3,975
Oklahoma	287	1,070	324	1,545
Oregon	20	68	20	68
Pennsylvania	749	2,385	576	2,156
South Carolina	577	1,715	594	1,499
Texas	896	6,414	1,061	6,578
Utah ²	127	1,086	94	432
Virginia	628	2,310	511	2,067
Total^{5,6}	12,378	67,149	11,765	53,594

¹ Revised.

² Includes extruded and other brick.

³ Extruded brick only.

⁴ Includes Montana only for 1991.

⁵ Other brick only.

⁶ Includes 1.5 million tons used in other brick production.

⁷ Data may not add to totals shown because of independent rounding.

TABLE 24
COMMON CLAY AND SHALE USED IN LIGHTWEIGHT AGGREGATE PRODUCTION IN THE
UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	Concrete block	Structural concrete	Highway surfacing	Other	Total	Total value
1990						
Alabama and Arkansas	708	85	11	—	804	10,729
California	78	99	—	—	177	723
Florida and Indiana	254	29	—	—	284	1,932
Kansas, Kentucky, Louisiana	246	229	15	67	557	1,741
Mississippi and Missouri	128	11	15	119	273	1,730
New York and Montana	259	41	—	—	300	2,069
North Carolina	245	82	—	—	327	3,659
Ohio, Oklahoma, Pennsylvania	246	37	1	—	284	2,014
Texas	66	157	222	31	473	2,518
Utah and Virginia	297	17	3	10	328	1,803
Total¹	2,524	786	268	227	3,804	28,918
1991						
Alabama and Arkansas	786	92	11	9	898	13,158
California	78	99	—	—	177	731
Florida and Indiana	227	23	—	—	250	1,616
Kansas, Kentucky, Louisiana	304	112	15	35	465	1,439
Mississippi and Missouri	89	8	14	105	216	1,518
New York and Montana	175	92	—	—	267	1,678
North Carolina	245	82	—	—	327	3,696
Ohio, Oklahoma, Pennsylvania	242	28	5	—	276	2,188
Texas	49	157	222	31	459	2,518
Utah and Virginia	243	15	6	—	264	1,472
Total¹	2,438	707	274	180	3,599	30,014

¹ Revised.

¹Data may not add to totals shown because of independent rounding.

TABLE 25
SHIPMENTS OF REFRACTORIES IN THE UNITED STATES, BY PRODUCT

Product	Unit of quantity	1989 ^a		1990	
		Quantity	Value (thousand)	Quantity	Value (thousand)
CLAY REFRACTORIES					
Superduty fire clay brick and shapes, other fire clay, including semisilica brick and shapes, glasshouse pots, tank blocks, feeder parts, upper structure parts used only for glass tanks	1,000 9-inch equivalent	59,725	\$49,177	55,536	\$50,085
High-alumina (50% to 60% Al ₂ O ₃) brick and shapes made of calcined diaspor or bauxite	do.	92,082	163,719	92,590	168,559
Insulating firebrick and shapes	do.	49,006	57,879	48,587	53,985
Ladle brick sleeves, nozzles, runner brick, tuyeres, hot-top refractories	short tons	62,972	48,839	56,072	47,316
Kiln furniture, radiant heater elements, potter's supplies, other miscellaneous-shaped refractory items	do.	35,701	37,261	32,975	37,997
Refractory bonding mortars	do.	80,139	43,189	81,175	73,595
Plastic refractories and ramming mixes, containing up to 87.5% Al ₂ O ₃	do.	227,633	92,779	228,599	96,388
Castable mixes	do.	299,292	128,721	283,500	114,323
Gunning mixes	do.	171,453	49,928	158,261	46,980
Other clay refractory materials sold in lump or ground form	do.	412,907	86,937	352,763	72,523
Miscellaneous refractories	do.	XX	64,837	XX	40,779
Total clay refractories	do.	XX	823,266	XX	802,530
NONCLAY REFRACTORIES					
Silica brick and shapes	1,000 9-inch equivalent	12,823	24,252	18,340	26,933
Magnesite and magnesite-chrome brick and shapes	do.	(¹)	(¹)	(¹)	(¹)
Chrome and chrome-chrome brick and shapes	do.	(¹)	(¹)	(¹)	(¹)
Shaped refractories containing natural graphite	short tons	23,197	44,575	21,145	47,778
Zircon and zirconia brick and shapes; other carbon refractories: Forsterite, pyrophyllite, dolomite-magnesite molten-cast, other brick and shapes	1,000 9-inch equivalent	31,341	183,446	33,484	200,074
Other mullite, kyanite, sillimanite, or andalusite brick and shapes	do.	3,231	26,279	3,269	25,809
Other extra-high (over 60% alumina) brick and fused bauxite, fused alumina, dense-sintered alumina shapes	do.	6,679	103,387	5,753	96,576
Silicon carbide brick, shapes, kiln furniture	do.	1,688	44,579	1,558	45,823
Refractory bonding mortar	short tons	W	19,474	W	19,068
Hydraulic-setting nonclay refractory castables	do.	31,022	32,778	30,538	40,293
Plastic refractories and ramming mixes	do.	123,934	90,462	123,199	92,333
Gunning mixes	do.	W	W	W	W
Dead-burned magnesia or magnesite	do.	322,023	82,736	295,167	79,185
Dead-burned dolomite	short tons.	202,692	12,073	224,280	13,457
Other nonclay refractory material sold in lump or ground form	do.	310,878	110,423	329,589	109,608
Miscellaneous nonclay refractories	do.	XX	413,219	XX	426,575
Total nonclay refractories	do.	XX	1,187,681	XX	1,223,512
Grand total refractories	do.	XX	2,010,947	XX	2,026,042

Revised. W Withheld to avoid disclosing company proprietary data, value included in total. XX Not applicable. Included in miscellaneous nonclay refractories.

Source: Bureau of Census Report Form MQ MA32C(90)-1, Current Industrial Reports—Refractory.

TABLE 26
U.S. EXPORTS OF CLAYS IN 1991, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	Ball clay		Bentonite		Fire clay		Fuller's earth		Kaolin		Clays, n.e.c. ¹		Total ²	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Argentina	—	—	(³)	15	(³)	8	—	—	6	1,795	(³)	568	7	2,386
Australia	—	—	28	1,910	23	1,603	(³)	22	9	3,482	1	1,857	61	8,873
Belgium-Luxembourg	—	—	9	1,922	(³)	51	(³)	39	102	17,006	3	2,388	114	21,405
Brazil	(³)	27	1	205	(³)	8	(³)	36	2	1,125	1	1,762	4	3,163
Canada	—	—	147	8,577	9	1,908	6	821	660	61,560	100	22,414	921	95,280
Chile	1	58	3	542	—	—	—	—	8	2,847	(³)	259	12	3,705
Colombia	—	—	7	525	(³)	34	—	—	11	2,918	1	448	20	3,925
Ecuador	—	—	1	138	—	—	—	—	4	561	1	307	6	1,007
Finland	—	—	2	183	—	—	(³)	4	245	36,475	6	487	253	37,149
France	—	—	1	543	(³)	181	(³)	64	10	2,118	1	454	13	3,361
Germany	(³)	9	13	1,162	(³)	52	(³)	53	47	8,780	6	5,623	66	15,680
Hong Kong	1	59	1	505	(³)	20	—	—	3	817	1	220	6	1,621
Italy	—	—	2	913	3	321	(³)	108	182	24,030	3	876	189	26,248
Japan	1	198	242	20,094	25	4,299	(³)	36	790	130,464	5	4,557	1,064	159,648
Korea, Republic of	(³)	5	6	2,058	1	337	(³)	44	108	23,559	2	1,199	117	27,203
Mexico	46	1,683	9	1,370	43	2,919	1	136	116	13,642	9	2,030	223	21,780
Netherlands	2	65	11	2,123	76	5,799	9	638	227	32,449	7	2,406	332	43,480
Peru	—	—	(³)	42	(³)	8	—	—	1	207	1	213	3	469
Philippines	2	138	2	459	—	—	—	—	3	743	1	549	9	1,888
Saudi Arabia	—	—	12	659	(³)	28	—	—	(³)	130	(³)	222	13	1,038
Singapore	—	—	15	1,693	—	—	2	341	2	467	4	1,506	22	4,007
South Africa, Republic of	—	—	2	209	(³)	4	1	213	21	5,148	1	644	25	6,217
Spain	—	—	1	229	—	—	1	208	7	1,667	(³)	232	9	2,336
Sweden	(³)	10	(³)	103	—	—	—	—	68	13,731	12	2,786	80	16,630
Switzerland	—	—	—	—	2	99	(³)	3	1	106	(³)	31	2	239
Taiwan	(³)	11	39	3,599	11	727	—	—	100	17,598	2	776	153	22,711
Thailand	—	—	5	686	—	—	—	—	14	3,140	(³)	549	20	4,375
United Kingdom	—	—	38	5,186	4	287	1	218	42	6,200	8	5,573	93	17,464
Venezuela	(³)	94	29	2,023	1	66	—	—	14	2,966	7	2,208	51	7,356
Other	5	566	33	5,892	1	221	4	1,455	48	14,556	8	6,811	106	29,531
Total ²	58	2,924	660	63,571	199	19,000	27	4,440	2,855	430,287	197	69,952	3,997	590,174

¹Also includes chamotte or dinas earth, activated clays and earths, and artificially activated clays.

²Data may not add to totals shown because of independent rounding.

³Less than 1/2 unit.

Sources: U.S. Department of Commerce.

TABLE 27
**U.S. IMPORTS FOR CONSUMPTION OF CLAYS
 IN 1991, BY KIND**

Kind	Quantity (metric tons)	Value (thousands)
China clay or kaolin:		
Canada	252	\$36
China	255	93
France	1	1
Germany	128	52
Italy	3	4
Japan	119	120
Korea	1	2
New Zealand	40	23
United Kingdom	2,574	1,276
Total	3,373	1,607
Fire clay:		
Canada	230	49
China	195	31
Total	425	80
Decolorizing earths and fuller's earth:		
Canada	26	10
Germany	46	24
Spain	9	11
United Kingdom	1	2
Total	82	47
Bentonite:		
Canada	1,037	387
Germany	248	605
Japan	27	72
Mexico	618	46
United Kingdom	294	161
Total	2,224	1,272
Common blue clay and other ball clay:		
France	3	5
United Kingdom	750	257
Total	753	262
Other clay:		
Canada	8,181	1,738
France	2	3
Germany	12	49
Italy	19	22
Japan	12	44
Thailand	6	6
United Kingdom	5,883	1,056
Total	14,115	2,918
Chamotte or dina's earth:		
France	6	3
Total	6	3

See footnote at end of table.

TABLE 27—Continued
**U.S. IMPORTS FOR CONSUMPTION OF CLAYS
 IN 1991, BY KIND**

Kind	Quantity (metric tons)	Value (thousands)
Artificially activated clay and activated earth:		
Austria	—	\$8
Belguim	10	10
Canada	226	204
Denmark	34	17
Germany	1,105	1,869
Japan	20	47
Mexico	12,808	4,608
Monaco	6	10
Netherlands	10	10
Switzerland	14	18
United Kingdom	62	219
Venezuela	52	11
Total	<u>14,346</u>	<u>7,031</u>
Grand total	<u>135,341</u>	<u>13,249</u>

Data do not add to total shown because of independent rounding.

Source: U.S. Department of Commerce.

TABLE 28
CLAYS: U.S. ANNUAL PRODUCTION CAPACITY,
DECEMBER 31, 1991, BY KIND AND TYPE

(Thousand metric tons)

Kind and type	Rated capacity ¹
Ball clay:	
Airfloat	635
Waterslurried	115
Unprocessed	300
Total	1,050
Bentonite:	
Nonswelling	555
Swelling	2,000
Total	2,555
Common clay and shale	38,000
Fire clay	1,100
Fuller's earth:	
Attapulgite	700
Montmorillonite	2,250
Total	42,050
Kaolin:	
Air-float	1,500
Calcined ²	555
Calcined ³	700
Delaminated	1,100
Unprocessed	1,000
Water-washed	4,100
Total	8,955
Grand total	54,610

¹Includes capacity at operating plants as well as at plants on standby basis.

²Low-temperature, filter.

³High-temperature, refractory.

TABLE 29
KAOLIN: WORLD ANNUAL
PRODUCTION CAPACITY,
DECEMBER 31, 1991, RATED
CAPACITY¹

(Thousand metric tons)

Country	Capacity
Algeria	16
Argentina	140
Australia	230
Austria	110
Bangladesh	14
Belgium	73
Brazil	820
Bulgaria	300
Burundi	*6
Chile	54
Colombia	1,360
Costa Rica	1
Czechoslovakia	730
Denmark	14
Ecuador	3
Egypt	140
Ethiopia (including Eritrea)	*5
France	1,450
Germany:	
Eastern states	650
Western states	180
Greece	160
Guatemala	5
Hong Kong	9
Hungary	41
India	740
Indonesia	150
Iran	*120
Israel	32
Italy	90
Japan	230
Kenya	*1
Korea, Republic of	910
Madagascar	6
Malaysia	115
Mexico	270
Mozambique	*1
Nigeria	1
Pakistan	45
Paraguay	64
Peru	9
Poland	55
Portugal	110

See footnotes at end of table.

TABLE 29—Continued
**KAOLIN: WORLD ANNUAL
 PRODUCTION CAPACITY,
 DECEMBER 31, 1991, RATED
 CAPACITY¹**

(Thousand metric tons)

Country	Capacity
Romania	450
South Africa, Republic of	200
Spain	500
Sri Lanka	11
Sweden	1
Taiwan	90
Tanzania	²
Thailand	275
Turkey	² 50
U.S.S.R.	3,100
United Kingdom	3,700
United States	8,955
Venezuela	27
Vietnam	1
Yugoslavia	270
Zimbabwe	¹
Total	27,293

¹Estimated.

²Includes capacity at operating plants as well as at plants on standby basis.

TABLE 31
**BENTONITE: WORLD ANNUAL
 PRODUCTION CAPACITY,
 DECEMBER 31, 1991, RATED
 CAPACITY¹**

(Thousand metric tons)

Country	Capacity
Algeria	36
Argentina	150
Australia	41
Brazil	250
Burma	1
Cyprus	² 80
Egypt	6
France	14
Greece	1,400
Guatemala	5
Hungary	91
Iran	² 30
Israel	6
Italy	360
Japan	500
Kenya	² (²)
Mexico	275
Morocco	4
Mozambique	²
New Zealand	5
Pakistan	45
Peru	27
Phillippines	27
Poland	77
Romania	190
South Africa, Republic of	75
Spain	140
Tanzania	² (²)
Turkey	¹ 100
U.S.S.R.	3,000
United States	2,555
Zimbabwe	¹ 120
Total	9,610

¹Estimated.

²Includes capacity at operating plants as well as at plants on standby basis.

³Less than 1/2 unit.

TABLE 30
**FULLER'S EARTH: WORLD ANNUAL PRODUCTION CAPACITY,
 DECEMBER 31, 1991, RATED CAPACITY¹**

(Thousand metric tons)

Country	Capacity
Algeria	4
Argentina	2
Australia (attapulgate)	16
Italy	41
Mexico	55
Morocco (smectite)	55
Pakistan	23
Sendgal (attapulgate)	120
Spain (attapulgate)	70
United Kingdom	300
United States	2,950
Total	3,636

¹Includes capacity at operating plants as well as at plants on standby basis.

TABLE 32
KAOLIN: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991 [*]
Algeria	16,000	17,800	*18,000	*20,000	*321,460
Argentina	*100,128	*93,871	*45,598	*50,000	50,000
Australia ⁴	176,958	159,067	*185,000	*200,000	190,000
Austria (marketable)	92,186	89,491	*85,312	*81,265	80,000
Bangladesh ⁵	12,272	10,097	7,092	*7,000	7,000
Belgium [*]	45,000	40,000	35,000	35,000	30,000
Brazil (beneficiated plus direct sales and direct use)	802,586	940,518	*974,000	*880,000	900,000
Bulgaria	281,000	220,000	*220,000	186,467	180,000
Burundi	5,290	4,021	4,305	5,281	5,000
Chile	44,533	54,464	58,512	32,416	*62,991
Colombia	366,300	408,141	540,000	*540,000	1,800,000
Czechoslovakia	697,000	685,958	698,000	670,550	650,000
Denmark (sales)	9,304	39,324	16,029	17,423	17,000
Ecuador	*11,017	*16,700	22,576	15,580	25,000
Egypt	125,256	124,122	121,515	49,032	50,000
Ethiopia (including Eritrea) ⁶	2,500	750	*390	*670	570
France (marketable) ⁷	*309,000	*338,000	*346,000	*367,000	370,000
Germany, Federal Republic of					
Eastern states (marketable) [*]	150,000	165,000	150,000	115,000	NA
Western states (marketable)	588,000	673,000	777,000	*684,000	NA
Total [*]	738,000	838,000	927,000	799,000	750,000
Greece	144,634	*127,395	67,234	*90,000	90,000
Guatemala	1,880	3,459	2,573	2,050	2,000
Hungary	33,289	29,572	24,824	*18,000	18,000
India:					
Salable crude	602,000	471,000	464,000	*631,000	*628,000
Processed	93,720	107,381	110,505	*104,000	110,000
Indonesia	122,046	147,109	157,122	*160,098	*139,915
Iran [*]	70,000	*100,000	*90,000	*45,000	60,000
Israel	*29,000	*30,600	*33,280	*42,212	40,000
Italy:					
Crude	*57,074	*71,522	*64,196	*67,321	67,500
Kaolinitic earth	22,194	*18,636	*18,924	17,946	17,500
Japan	172,781	*167,771	*155,073	*164,802	*129,942
Kenya	40	42	42	—	(^o)
Korea, Republic of	630,945	832,110	1,219,174	1,446,598	*1,755,255
Madagascar	1,427	365	1,315	485	500
Malaysia	96,882	116,869	108,347	152,972	*186,699
Mexico	151,104	162,415	141,519	*156,140	*166,640
Mozambique [*]	151	200	200	(^o)	—
New Zealand	25,548	29,649	26,324	*30,000	25,000
Nigeria	*250	*250	550	1,356	1,300
Pakistan	32,208	41,968	39,907	61,630	62,000
Paraguay [*]	72,000	76,000	74,000	74,000	74,000
Peru	626	8,849	*7,000	*8,000	8,000
Poland	49,000	*59,000	50,000	*48,000	45,000
Portugal	66,763	71,200	58,297	73,849	74,000
Romania [*]	400,000	400,000	400,000	*250,000	200,000

See footnotes at end of table.

TABLE 32—Continued
KAOLIN: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991 ³
South Africa, Republic of	151,730	¹ 152,500	139,711	132,421	³ 133,674
Spain (marketable) ⁴	433,077	438,160	⁴ 436,335	⁴ 435,000	400,000
Sri Lanka	6,869	7,100	7,761	7,731	⁵ 7,737
Sweden	100	92	⁶ 100	⁶ 100	100
Taiwan	67,525	81,879	98,115	⁷ 105,084	⁸ 92,970
Tanzania	1,446	528	1,554	⁹ 2,021	2,000
Thailand	206,568	269,976	328,824	347,690	³ 381,839
Turkey	126,119	204,478	² 238,251	230,000	240,000
U.S.S.R. ⁶	2,000,000	2,000,000	2,000,000	1,800,000	1,600,000
United Kingdom	3,058,821	3,276,795	³ 3,139,672	³ 3,037,486	3,000,000
United States ⁹	8,007,919	8,973,097	8,973,668	9,761,775	⁸ 9,575,000
Venezuela	30,000	² 28,000	15,000	12,000	³ 39,000
Vietnam ⁶	1,000	700	750	750	800
Yugoslavia	218,851	218,673	² 260,141	¹ 198,513	170,000
Zimbabwe	780	95	15	—	—
Total	²21,020,697	²22,805,759	²23,258,632	²23,672,714	24,733,392

¹Estimated. ²Revised. NA Not available.

³Table includes data available through July 20, 1992.

⁴In addition to the countries listed, China, Lebanon, Morocco, and Suriname may also have produced kaolin, but information is inadequate to make reliable estimates of output levels.

⁵Reported figure.

⁶May include ball clay and other clays grouped for statistical purposes as kaolin.

⁷Data for year ending June 30 of that stated.

⁸Data for year ending July 6 of that stated.

⁹Includes kaolinitic clay.

¹⁰Includes crude and washed kaolin and refractory clays not further described.

¹¹Kaolin sold or used by producers.

TABLE 33
BENTONITE: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991 [*]
Algeria ³	[†] 24,600	[†] 25,600	[†] 39,200	[†] 41,600	[†] 25,806
Argentina	108,595	173,930	[†] 150,000	[†] 150,000	100,000
Australia ³	30,392	35,671	[†] 35,000	[†] 35,000	35,000
Brazil	216,591	[†] 147,149	146,550	[†] 167,618	160,000
Burma	297	418	711	[†] 700	700
Chile	—	529	2,005	[†] 2,207	[†] 1,054
Cyprus	79,600	90,300	[†] 59,744	[†] 81,800	[†] 58,500
Egypt	3,827	3,166	3,512	[†] 3,500	3,500
France [*]	8,000	8,000	8,000	10,000	10,000
Germany, Federal Republic of	167,000	197,000	200,000	[†] 230,000	230,000
Greece	1,300,525	730,501	[†] 1,096,177	[†] 1,000,000	1,000,000
Guatemala	24,782	973	8,236	[†] 9,000	12,000
Hungary	98,331	66,014	59,973	[†] 36,600	35,000
Indonesia	7,962	8,266	3,863	5,914	[†] 21,512
Iran ⁵	[†] 52,523	[†] 37,028	[†] 31,547	[†] 51,096	52,000
Israel (metabentonite) [*]	[†] 4,500	[†] 3,000	[†] 3,500	[†] 3,500	3,500
Italy	[†] 305,622	[†] 319,127	[†] 234,212	[†] 228,153	230,000
Japan	468,705	455,137	526,131	549,414	[†] 554,145
Kenya [*]	200	200	—	—	—
Mexico	129,596	163,916	123,927	[†] 144,895	[†] 134,384
Morocco	2,948	3,445	3,970	[†] 3,900	3,900
Mozambique	936	986	126	([†])	—
New Zealand (processed)	—	1,255	1,342	[†] 1,393	1,500
Pakistan	2,537	4,880	5,466	3,235	3,500
Peru	16,194	50,741	[†] 40,000	[†] 40,000	55,000
Philippines	759	2,030	2,782	16,484	16,000
Poland [*]	75,000	80,000	80,000	80,000	70,000
Romania [*]	180,000	180,000	180,000	[†] 150,000	120,000
South Africa, Republic of ⁶	48,953	66,750	62,987	66,059	[†] 64,600
Spain	103,420	103,753	[†] 143,398	[†] 145,000	145,000
Tanzania [*]	75	75	75	75	75
Turkey	89,262	80,218	[†] 93,256	[†] 100,000	100,000
U.S.S.R. [*]	2,900,000	2,900,000	2,900,000	2,700,000	2,400,000
United States	2,545,775	2,870,971	3,112,365	3,473,595	3,432,000
Yugoslavia	154,288	125,069	[†] 128,593	[†] 102,681	85,000
Zimbabwe ⁶	116,802	113,157	104,865	99,854	100,000
Total	[†] 9,268,597	[†] 9,049,255	[†] 9,591,513	[†] 9,733,273	9,263,676

^{*}Estimated. [†]Revised.

¹Table includes data available through July 20, 1992.

²In addition to the countries listed, Canada and China are believed to produce bentonite, but output is not reported, and available information is inadequate to make reliable estimates of output levels.

³Includes bentonitic clays.

⁴Reported figure.

⁵Year beginning Mar. 21 of that stated.

⁶May include other clays.

TABLE 34
FULLER'S EARTH: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991 ³
Algeria ⁴	3,500	3,500	3,500	¹ 37,840	⁴ 4,526
Argentina ⁴	2,000	2,000	2,000	2,000	2,000
Australia (attapulgitite) ⁴	⁴ 10,960	15,000	15,000	20,000	15,000
Germany, Federal Republic of: Western states (unprocessed)	677,000	670,000	⁶ 636,000	⁶ 653,000	760,000
Italy	³ 38,150	38,955	43,550	⁴ 45,800	45,000
Mexico	49,112	37,226	24,603	² 29,865	² 27,800
Morocco (smectite)	46,271	52,694	48,820	45,230	45,000
Pakistan	17,945	12,395	15,436	16,489	17,000
Senegal (attapulgitite)	111,048	118,725	98,882	¹ 114,610	115,000
South Africa, Republic of (attapulgitite)	6,026	7,161	6,609	7,628	⁸ 8,109
Spain (attapulgitite)	40,818	43,585	² 23,990	¹ 25,000	25,000
United Kingdom ⁴	213,000	² 213,000	210,000	205,000	208,000
United States ⁴	1,865,890	1,792,232	1,881,511	2,307,475	2,740,000
Total	³ 3,081,720	³ 3,006,473	³ 3,009,901	³ 3,479,937	4,012,435

⁴Estimated. ²Revised.

¹Excludes centrally planned economy countries and former such countries, some of which presumably produce fuller's earth, but for which no information is available. Table includes data available through July 20, 1992.

²In addition to the market economy countries listed, France, India, Iran, Japan, and Turkey have reportedly produced fuller's earth in the past and may continue to do so, but output is not reported, and available information is inadequate to make reliable estimates of output levels.

³Reported figure.

⁴Sold or used by producers.

FIGURE 1
KAOLIN SOLD OR USED BY DOMESTIC PRODUCERS FOR SPECIFIED USES

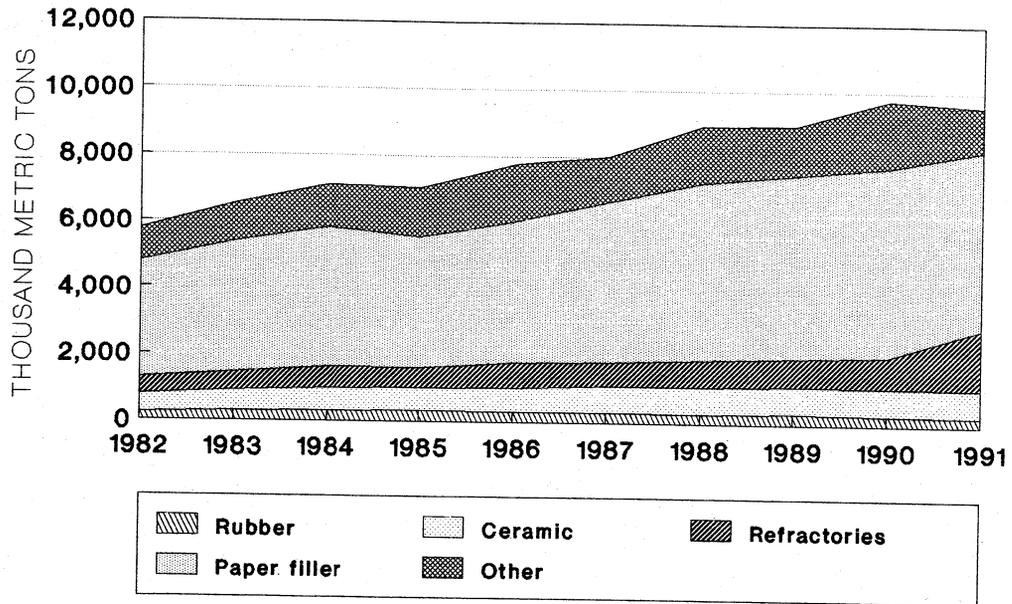


FIGURE 2
BENTONITE SOLD OR USED BY DOMESTIC PRODUCERS FOR SPECIFIED USES

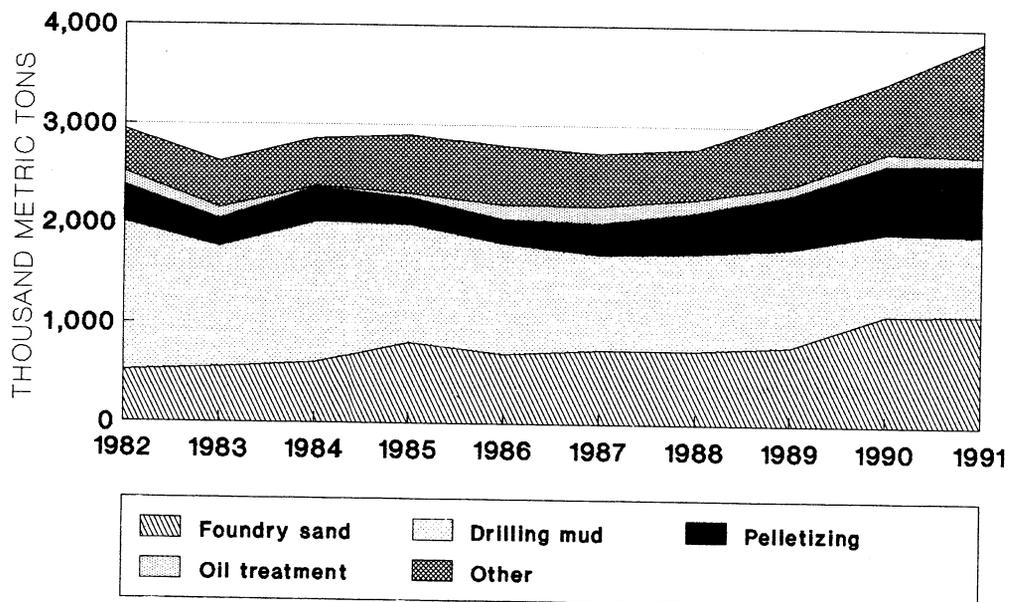
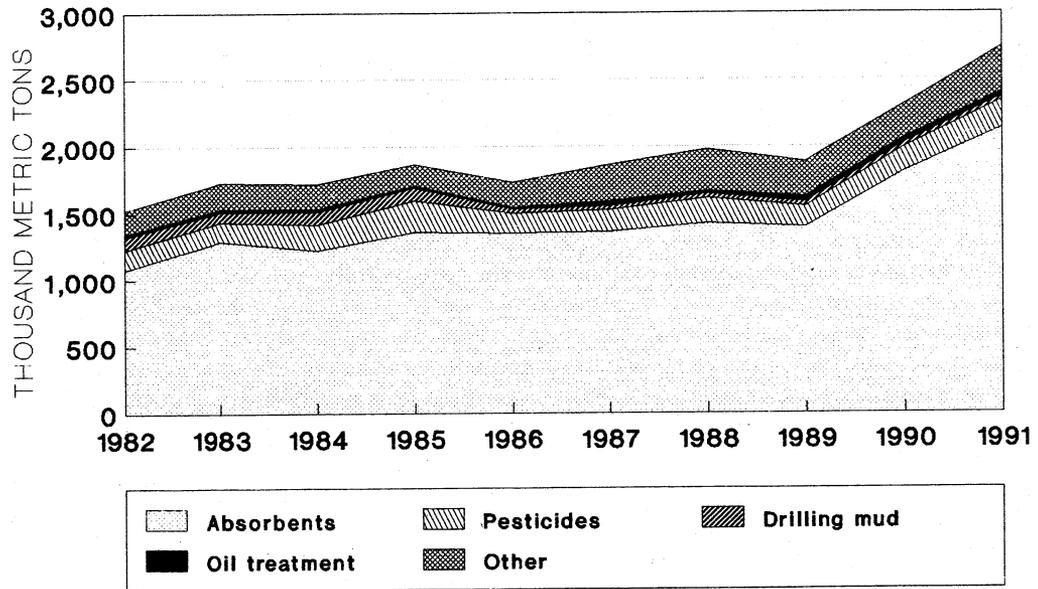


FIGURE 3
FULLER'S EARTH SOLD OR USED BY DOMESTIC PRODUCERS FOR SPECIFIED USES



COBALT

By Kim B. Shedd

Ms. Shedd is a physical scientist (geologist) with more than 12 years of combined experience working for the U.S. Bureau of Mines in research and mineral commodities. She has been the commodity specialist for cobalt since 1988. Domestic survey data and trade data were prepared by Robin A. Johnson, mineral data assistant. International production tables were prepared by William L. Zajac, Chief, Section of International Data, and Ronald Hatch, international data assistant, in coordination with the Bureau's country specialists.

Cobalt is a strategic and critical metal used in many diverse industrial and military applications. The largest use of cobalt is in superalloys, which are alloys designed to resist stress and corrosion at high temperatures. The main use for superalloys is in jet engine parts. Another important use of cobalt is to make permanent magnets, which are used in a wide range of electrical devices. Cobalt acts as a binder in cemented carbides and diamond tools, which are used for metal cutting and forming, mining, and oil and gas drilling. Cobalt chemicals have diverse uses, including catalysts for the petroleum and chemical industries; drying agents for paints, varnishes, and inks; additives to ground coats for porcelain enamels; and pigments for ceramics, paints, and plastics.

The United States is the world's largest consumer of cobalt, but has no domestic production, so it relies on imports to meet its primary cobalt needs. The United States stocks significant quantities of cobalt metal in the National Defense Stockpile (NDS) for military, industrial, and essential civilian use during a national emergency.

For the fourth year in a row Western World cobalt demand exceeded Western World production. Zaire and Zambia, the world's two leading producers, began the process of democratization following decades of single-party rule. Zambia had a smooth transition to a new Government late in the year. Zaire, however, suffered from political discord resulting

from delays in converting to a multiparty system. In addition to political tensions, economic conditions in Zaire worsened, resulting in social unrest. In this framework of political and economic problems, La Générale des Carrières et des Mines du Zaire (Gécamines), the world's largest cobalt producer, tried to bring back production levels reduced by a major mine collapse that occurred in 1990. The company was unable to meet its production targets for cobalt, resulting in a further drawdown of already low producer stocks and an inability to complete its 1991 deliveries.

Concern over adequacy of supply caused free market prices to double in the latter part of the year. During the year, Japanese consumers built up significant stocks in fear of a shortage, resulting in a 50% increase in demand from that country. The Western World supply-demand imbalance would have been worse, were it not for recessionary economic conditions in consuming countries and a significant influx of cobalt from the U.S.S.R., which sold both Russian-produced and Government-stockpiled cobalt to Western markets.

DOMESTIC DATA COVERAGE

Domestic data on cobalt processing and consumption are developed by the U.S. Bureau of Mines from three separate, voluntary surveys of U.S. operations. In the cobalt processors survey, seven of the eight companies canvassed responded.

Most of the data on cobalt used in chemicals were obtained from this survey. The second survey covers a broad range of metal-consuming companies, such as superalloy producers, magnetic alloy producers, and tungsten carbide producers. The U.S. Bureau of Mines also surveys superalloy scrap recyclers to determine the consumption of secondary cobalt in superalloy production. Seven of the 13 recyclers on the survey responded to requests concerning the quantity of cobalt contained in scrap processed and sold to superalloy producers. The data in tables 3 through 6 contain estimates to account for nonrespondents.

BACKGROUND

Definitions, Grades, and Specifications

Cobalt is a metallic element. It is silvery gray in color, hard, ductile, somewhat malleable, and magnetic. Other properties include atomic number, 27; atomic weight, 58.93; melting point, 1,493° C; boiling point, 3,100° C; and Curie temperature, 1,121° C. Cobalt-60 (⁶⁰Co) is produced by irradiating cobalt metal in a nuclear reactor. This radioactive isotope is used in radiation therapy and sterilization of medical supplies.

Currently, there are no internationally recognized specifications for cobalt metal. The two leading Western World producers, Gécamines and Zambia

Consolidated Copper Mines Ltd. (ZCCM), have proposed specifications for five grades of cobalt.¹ The U.S. Government has purchase specifications for NDS cobalt. The current NDS specification, P-13-R6, provides physical and chemical requirements for three grades of refined cobalt metal. Grades A and B must be in the form of electrolytic cathode; grade C can be either cathode or granules. Chemical requirements specify the weight percentage, in order of abundance, of cobalt, nickel, iron, and manganese, as well as maximum levels of 26 impurities.

Products for Trade and Industry

Roughly one-half of the cobalt used in the United States is consumed as primary cobalt metal. Most of this metal is in the form of electrolytic cobalt (cathode or rounds), granules (shot), or metal powder. Some of the Russian cobalt metal is in ingot form and some of the Zambian cobalt is produced as crushed bar. Secondary cobalt is cobalt recovered from scrap. Purchased scrap constituted about 22% of U.S. reported consumption in 1991. The remainder of the cobalt used, about 30%, is in the form of cobalt chemical compounds. This includes cobalt oxide, which can be either gray oxide, with 75% to 78% cobalt content, or black oxide, with 70% to 74% cobalt content. The percent cobalt content in the oxides depends on the relative amounts of cobalt(II)oxide, CoO, and cobalt(II)dicobalt(III)tetroxide, Co₃O₄, present. Commercially available inorganic cobalt compounds include carbonate, chloride, hydroxide, nitrate, and sulfate (either as heptohydrate or monohydrate). Most of the inorganic compounds are sold in crystalline form, but some are also available in solution. A variety of organic cobalt compounds are also available.

Industry Structure

Cobalt mine and refinery production are limited to a few countries. The United States is not currently a cobalt producer. U.S. mine production of

cobalt ceased at the end of 1971, and the sole U.S. cobalt refinery discontinued processing imported nickel-cobalt matte in late 1985. In 1991, Zaire was the world's leading producer of refined cobalt, followed by Zambia, the U.S.S.R., Canada, Norway, and Finland. These six countries represented 96% of world cobalt refinery production. Zairian and Zambian production was from domestic ores. Canada and the U.S.S.R. produced cobalt from both domestic and imported raw materials. All of the cobalt produced in Norway and most of the cobalt produced in Finland was from imported raw materials. World producers of refined cobalt and producers of intermediate cobalt-containing products are listed. (See tables 1 and 2.)

Cobalt processors represent an important source of supply for various industries. Processors differ from producers primarily in the feed materials they use. Cobalt producers refine cobalt from ores, concentrates, mattes, or residues originating from mining or refining operations. A few refiners supplement their feedstock with secondary cobalt (scrap). Producer products include cobalt cathode, granules, metal powder, oxide, and salts. In contrast, cobalt processors begin with refined cobalt metal or cobalt-containing scrap and make metal powder, oxide, and/or salts, but not cathode or granules. The world's largest cobalt processor is Metallurgie Hoboken-Overpelt S.A. (MHO) in Belgium. Other cobalt processors are in Asia, Europe, and the United States (see Production section of this report).

Byproducts and Coproducts

Cobalt is rarely produced as a primary product from a mining operation. Most of Western World cobalt supply is produced as a byproduct of copper production in Zaire and Zambia. With the exceptions of Morocco, where small amounts of cobalt are produced as a primary product, and the Republic of South Africa, where cobalt is produced as a byproduct of platinum mining and refining, cobalt production in most other

countries is a byproduct of nickel production.

Economic Factors²

Most of cobalt's production costs are attributed to the primary metal produced at a given operation. The incremental costs applied to cobalt production include costs to separate cobalt from the primary metal, usually during the refining stage; transportation costs; and marketing costs. The U.S. Bureau of Mines Minerals Availability Program estimated 1989 direct operating costs for cobalt refining in market economy countries to range from less than \$1.00 per pound for cobalt cathode production at Falconbridge Ltd.'s Kristiansand, Norway, refinery to about \$3.00 per pound for production of cobalt metal powders at Sherritt Gordon Ltd.'s refinery in Alberta, Canada. Cobalt refining costs in Zaire and Zambia are estimated to average about \$2.50 per pound. However, additional capital improvements, transportation, and marketing expenses in these two countries may increase total costs to about \$4.00 per pound. Most of the nonproducing properties evaluated in the study would require a total cost per pound, including a 15% discounted cash-flow rate of return, in excess of January 1989 market prices for the primary commodities (\$1.50 per pound for copper, \$7.50 per pound for nickel, or \$8.65 per pound for cobalt).

Operating Factors

The Environmental Protection Agency (EPA) regulates releases of cobalt into the environment under various programs. Workplace exposures are regulated by the Occupational Safety and Health Administration (OSHA).

ANNUAL REVIEW

Legislation and Government Programs

The Defense Logistics Agency (DLA) reported a yearend NDS cobalt inventory of 24,126 metric tons, contained cobalt. This included cobalt received from

Sherritt-Gordon Ltd. during the 1990 cobalt upgrading program that underwent a final accounting transfer during 1991.

The NDS goal of 38,737 metric tons of cobalt metal remained in effect during 1991. However, in July, the DLA submitted an interim report to Congress that proposed new goals for 39 materials, including cobalt. The new goals were intended to reflect a reduction in the potential threat to U.S. national security. They were developed using 1989 supply and demand data, following the existing statutory requirement that NDS planning be based on a 3-year global conventional war with a 1-year mobilization period. The proposed goal for cobalt was 20,593 metric tons of cobalt metal. Adoption of this goal would result in an excess of about 3,500 metric tons of cobalt. Before any sales of excess materials could occur, Congress must approve the proposed goals, and, in the case of cobalt, pass legislative authority for the disposals. By law, disposals of NDS materials must be made in a manner to avoid undue market disruption. Goals proposed in the interim report are subject to revision in the 1992 Report to the Congress on National Defense Stockpile Requirements.

In July, the President terminated sanctions against the Republic of South Africa implemented under the Comprehensive Anti-Apartheid Act of 1986 (Public Law 99-440). The President determined that the Government of South Africa had taken all of the steps specified in section 311(a) of the act, and therefore, that title III and sections 501(c) and 504(b) of the act had terminated.³ Cobalt had been certified as a strategic mineral by the U.S. State Department, so that it had been exempt from the prohibition of imports of products "produced, manufactured by, marketed, or otherwise exported by a parastatal organization of South Africa."

Strategic Considerations

Cobalt is considered a strategic and critical metal because of its many industrial and defense-related uses and because the United States is highly dependent on imports for its supply. The

United States is the world's largest consumer of cobalt. In 1991, the United States consumed about 30% of estimated world refinery production. There was no domestic production, so demand was met primarily from imports, with the exception of about 20% from purchased scrap.

To ensure an adequate supply for military, industrial, and essential civilian needs, cobalt metal is included in the NDS. Stockpile quantities are intended to sustain the United States for a period of not less than 3 years during a national emergency situation. Most of the cobalt in the stockpile was purchased prior to 1980 and does not meet current quality requirements for vacuum-melted superalloys.

World cobalt production is concentrated in a limited number of geographic areas. More than one-half of the world's supply of refined cobalt comes from central Africa, primarily Zaire and Zambia. Since 1987, all of the cobalt produced in Zaire has been transported through the Republic of South Africa. Cobalt produced in Zambia was formerly transported through the Republic of South Africa, but has been exported through Dar es Salaam, Tanzania, in recent years. Therefore, while the Republic of South Africa is not a major cobalt producer, its potential influence on supply is great because of the large amounts of cobalt exported using its transportation system. The United States formerly prohibited imports of products "produced, manufactured by, marketed, or otherwise exported by a parastatal organization of South Africa" as part of the Comprehensive Anti-Apartheid Act of 1986. However, cobalt was identified as strategic and critical mineral by the U.S. Department of State and exempted from this prohibition. In July, the President lifted the sanctions against South Africa (see Legislation and Government Programs section of this report).

Production

There was no domestic mine or refinery production of cobalt in 1991. Blackbird Metals Inc. of New York

continued with its efforts to initiate U.S. cobalt production. The company postponed its plan to purchase and reopen the former Blackbird cobalt mine in Idaho, but continued with plans to build a cobalt refinery with an annual capacity of 5,000 metric tons per year. The company intended to use a variety of cobalt-containing materials as feed for the refinery.

The State of Maine's Department of Environmental Protection finalized new regulations for the exploration and mining of metallic minerals in August. During the third quarter, Black Hawk Mining Inc. of Toronto, Canada, began the permitting process for its Knox nickel-copper-cobalt deposit near Warren, ME. The company recalculated the ore reserves at a 0.8% nickel cutoff grade, with the following results: 3,970,000 metric tons geological ore reserves grading 1.40% nickel, 0.64% copper, and 0.12% cobalt.⁴ The company planned to mine the deposit by both open pit and underground methods at the rate of 420,000 tons of ore per year. Knox Nickel would produce a bulk concentrate that would be exported to be refined. Annual production of payable metals was estimated at 3,400 metric tons of nickel, 2,000 metric tons of copper, and 160 metric tons of cobalt.

U.S. cobalt supply included secondary cobalt from the recycling of superalloy and other forms of scrap. Cobalt was recovered from spent petroleum catalysts at the AMAX Metals Recovery plant in Braithwaite, LA, and by Gulf Chemical and Metallurgical Corp. in Freeport, TX.

Two cobalt processors produced extra-fine cobalt metal powder in the United States. Carolmet, owned by MHO of Belgium, produced extra-fine powder from imported primary metal at its Laurinburg, NC, plant. GTE Products Corp. produced extra-fine powder from recycled materials in Towanda, PA. Production and shipments of extra-fine cobalt metal powder are withheld to avoid disclosing company proprietary data.

Domestic cobalt processors produced 2,039 metric tons of cobalt oxide and hydroxide, inorganic cobalt compounds, and organic cobalt compounds in 1991.

Because this figure includes production of intermediate forms, it does not represent net production. Shipments are defined as sales, transfers, or consumption to make end-use products such as paint driers or catalysts. In 1991, domestic cobalt processors shipped 1,886 metric tons of cobalt oxide and hydroxide, inorganic cobalt compounds, and organic cobalt compounds. Production and shipments each decreased 4% in 1991 as compared with production and shipments in 1990.

Consumption and Uses

Apparent consumption, as calculated from net imports, consumption from purchased scrap, and changes in Government and industry stocks, was 7,786 metric tons. (See table 3.)

The data for cutting and wear-resistant materials in table 4 have been revised. The category titled "Cutting and wear-resistant materials" now represents only those products made from cobalt metal powder—such as cemented carbides and diamond tools. Wear-resistant alloys such as stellites have been removed from this category and are combined with similar alloys under the category titled "Welding materials (structural and hardfacing)." As a result of this revision, cemented carbides and diamond tools now average about 7% of total reported consumption and wear-resistant alloys about 2%. (See table 4.)

U.S. reported cobalt consumption decreased 4% in 1991 compared with that of 1990. Total reported consumption has been relatively level since 1988. In 1991, the amount of cobalt consumed as metal decreased to below 50% of all forms consumed, while cobalt consumed in scrap increased to more than 20% and cobalt consumed as chemicals remained about 30%. (See table 5 and figure 1.)

Metallurgical industries (producers of cemented carbides, magnetic alloys, mill products, steels, superalloys, etc.) consumed 3% less cobalt in 1991 as compared with consumption in 1990. Superalloy melters used 8% less cobalt than the record-high amount used in 1990. However, the amount of cobalt consumed in superalloys remained above

consumption levels reported prior to 1990. Producers of cutting and wear-resistant materials used slightly less cobalt in 1991 than they did in 1990. In contrast, producers of magnetic alloys used basically the same amounts of cobalt in both years.

Cobalt consumption by chemical industries decreased 4% in 1991. As compared with consumption in 1990, in 1991 more cobalt was consumed as glass decolorizers, ground coat frits, and paint driers, while less cobalt was consumed to make catalysts, feed, and pigments.

Stocks

Total yearend cobalt stocks held by U.S. processors and consumers decreased 12% as compared with 1990 yearend stocks. The largest decrease was in cobalt metal stocks, at 20% below yearend 1990 levels. Yearend chemical stocks were only slightly below 1990 yearend levels. In contrast, yearend scrap stocks were 43% greater in 1991 than at yearend 1990. (See table 6.)

Stocks held by producers' sales agents in the United States were believed to be very low during 1991.

Markets and Prices

In 1991, Western World cobalt demand exceeded Western World production for the fourth consecutive year. During previous years, the deficit was met primarily from producers' stocks. In 1991, the remaining producer stocks continued to be drawn down, but imports of cobalt from the U.S.S.R.—both Russian-produced and cobalt from the Soviet strategic stockpile—made a significant contribution to Western cobalt supply. Estimates of the quantity of cobalt from the U.S.S.R. that entered Western markets in 1991 ranged from 1,000 to 3,000 metric tons. The combined effects of increased imports from the U.S.S.R. and reduced consumption because of recessionary economic conditions lessened the impact of the imbalance between production and demand. The effect of economic conditions on Western World

consumption was obscured somewhat by strong Japanese demand resulting from stockbuilding (see Japan section of this report).

The producer price of cobalt was maintained at \$11.00 per pound throughout 1991. In contrast, free market prices doubled during the latter part of year, approaching levels last seen during the "cobalt crisis" of 1978-79. Free market prices in January ranged from \$15.25 to \$16.50 per pound. In spite of ongoing concerns over cobalt supplies in general, and the impact of the worsening political situation in Zaire in particular, prices steadily decreased during the first half of 1991. In late July, free market prices dropped below \$13.00 per pound, before increasing to \$13.50 to \$14.00 in August. During the second week in September, prices increased to about \$15.00 per pound, reportedly because of renewed demand, speculation over the upcoming announcement of the 1992 producer price, and concern over increased unrest in Zaire. In late September/early October, free market prices jumped sharply to almost \$20.00 per pound following reports of looting and rioting in Zaire, which caused the evacuation of foreign nationals and a temporary halt in copper and cobalt production. At this time, Gécamines reduced its 1991 production forecast to 12,000 metric tons from the 13,500 metric tons originally targeted for the year.

During the second week of October, Gécamines and ZCCM announced a new 1992 producer price of \$13.00 per pound, effective January 1, 1992. Unlike past years when the producer price was effective for 1 to 2 years, the 1992 price was to be reviewed in June 1992 and subject to change at that time. Free market cobalt prices dropped back to the \$17.00 to \$18.00 range, but then rapidly increased to almost \$30.00 per pound during November because of concerns over future supply from both Zaire and Zambia. News from Zaire of renewed violence and a second production stoppage in late October was followed by reports of suspended cobalt deliveries. In Zambia, the election of a new president

in the country's first multiparty elections since independence caused speculation that new ZCCM management might change the company's cobalt marketing policy.

In mid-December, Gécamines and ZCCM revised their 1992 producer price to \$25.00 per pound. The new price superseded the \$13.00 price announced in October, and like the earlier price, was subject to evaluation and possible revision in mid-1992. The increase was intended to bring producer prices closer to free market prices, which were then in the \$30.00 to \$35.00 per pound range. The new price would bring much-needed income to producer countries in the short term, but could result in substitution in some applications and decreased markets in the long term.

At yearend, market concerns continued to focus on Gécamines' production levels. The company estimated 1992 refinery production at 8,000 to 9,000 metric tons, but industry analysts suggested that production could be lower. As a result of the lower production, Gécamines informed contract customers that 1992 deliveries would be only 60% of 1991 contracted amounts.

The weighted average market price for the year was \$16.92 per pound. Prices for cobalt-containing materials are presented. (See tables 3 and 7 and figure 2.)

Foreign Trade

U.S. imports of unwrought cobalt and cobalt in chemicals increased in 1991 to an estimated 6,924 metric tons valued at \$174 million. (See tables 8 and 9.) This represents an 8% increase over imports for consumption in 1990, excluding 1990 imports for the NDS. Fifty-eight percent of U.S. cobalt imports in 1991 was from ores originating in the south-central African countries of Zaire and Zambia. This included cobalt imported from Belgium, where Zairian cobalt metal was processed into metal powder, oxides, and salts by MHO. Twenty-eight percent of U.S. imports was from Canada and Norway. Much of the cobalt produced in Norway was from Canadian ores.

Imports of cobalt metal from the U.S.S.R. increased to 285 metric tons or 4% of total imports. The U.S.S.R. is a major cobalt producer, but did not export cobalt to the United States before 1990. U.S. cobalt imports by source are presented in figure 3.

U.S. net import reliance as a percentage of apparent consumption was estimated to be 80% in 1991. The net import reliance would be 100% if no cobalt were recovered from secondary sources (scrap). (See tables 8, 9, 10, and 11 and figure 3.)

In 1991, the United States exported an estimated 1,536 metric tons of unwrought cobalt and cobalt contained in chemicals valued at \$30.5 million. This represented a 15% increase as compared with exports in 1990. One-half of this cobalt was shipped to five countries: Canada (13%), Mexico (13%), Japan (11%), Italy (7%), and the United Kingdom (6%). The remaining 50% was shipped to 41 other countries. (See table 12.)

Exports also included 323 metric tons, gross weight, of wrought metal and cobalt articles valued at \$13.4 million. Ninety percent of these materials was sent to seven countries: the Netherlands (25%), Canada (14%), France (13%), Sweden (12%), Japan and the United Kingdom (each 10%), and the Republic of Korea (7%). The remainder was shipped to 18 other countries. In addition, the United States exported 9 metric tons, gross weight, of material under the category entitled, "Cobalt ores and concentrates." Canada received 4.5 metric tons of this material valued at \$40,568. A shipment to Belgium of 4.3 metric tons valued at \$190,040 could not be verified by the Bureau of Census.

World Review

World cobalt production decreased in 1991. Refinery production reported by the seven Cobalt Development Institute (CDI) member producers⁵—Falconbridge, Gécamines, Inco Ltd., Outokumpu Oy, Sherritt Gordon, Sumitomo Metal Mining Co. Ltd., and ZCCM—decreased 4% from production in 1990. The decrease was the result of a significant decrease in

production by Gécamines—the world's largest cobalt producer. Production in 1991 by Inco Ltd. and ZCCM was essentially unchanged from that of 1990. In contrast, Sherritt Gordon, Outokumpu Oy, and Falconbridge each produced significantly more cobalt in 1991 than in 1990. The CDI estimated total 1991 world production at 25,300 metric tons, with nonmember production primarily from Russia (4,300 metric tons) and China (300 metric tons) and the remaining 400 metric tons from miscellaneous other countries. The CDI estimated world consumption at about 25,500 metric tons, roughly in balance with world production.

Capacity.—The data in table 13 are rated capacity for refineries as of December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. Because not all countries or producers make production capacity information available, historical reported or estimated cobalt production data have been used to estimate refinery capacity in some cases. Changes in refinery capacity can result from changes in facilities or from changes in knowledge about the facilities. (See table 13.)

Australia.—Nickel-cobalt sulfide and cobalt sulfide were produced as byproducts of nickel mining and refining by Western Mining Corp. (WMC) in Western Australia and Queensland Nickel Pty. Ltd. in Queensland, respectively. Minor amounts of cobalt oxide were produced as a byproduct of zinc production by Pacific Smelting and Mining Co. Ltd. in Risdon, Tasmania.

Dallhold Investments Pty. Ltd., owner of 72% interest in the Queensland Nickel Joint Venture, went into receivership in July. Operation of Queensland Nickel's Yabulu nickel-cobalt refinery continued under the control of a consortium of financial institutions—Hongkong and Shanghai Corp., Bank of New Zealand Ltd., and Tricontinental Corp. Ltd. In October, the consortium put its 72% interest up for sale. The remaining 28% interest, owned by the Queensland government, was not affected by the sale. Cobalt sulfide produced at the Yabulu refinery was refined by Outokumpu Oy in Finland.

MIM Holdings Ltd. continued work on a pilot circuit to recover cobalt from its Mount Isa copper concentrates. The circuit would use bioleaching technology to produce cobalt as hydroxide. The hydroxide would then be sold for further refining. Trial runs were expected to begin during the third quarter of 1992. If the pilot circuit proved successful, an annual production of between 600 and 1,200 metric tons of cobalt might be possible by mid-1994.⁶

Belgium.—In December, MHO, the world's largest cobalt chemical and metal powder processor, informed its customers that it would withdraw from the cobalt salts market in 1992. The company planned to continue producing cobalt oxides and metal powders, but would no longer produce cobalt salts such as acetates, chlorides, sulfates, carbonates, and nitrates. Industries using cobalt salts would have to obtain them from other sources. Applications for cobalt salts include catalysts, ceramics, enamels, magnetic recording media, metal finishing, rubber additives, and feed for the manufacture of other chemicals, including driers for paints and inks. MHO's decrease in production was the result of reduced supplies of raw materials. Gécamines is the primary source of cobalt metal feed for MHO's cobalt plant at Olen. The company was expected to resume salts production when raw materials supply problems were resolved.

Botswana.—BCL Ltd. mined nickel-copper ores from company mines in the Selebi-Phikwe district. Copper-nickel-cobalt matte produced by BCL Ltd. was sent to refineries in Norway and Zimbabwe to be refined.

Brazil.—Cia. Niquel Tocantins produced cobalt cathode at its nickel refinery in Sao Miguel Paulista, Sao Paulo State.

Canada.—Cobalt is produced as a byproduct of nickel by three Canadian companies, Falconbridge, Inco, and Sherritt-Gordon.

In 1991, Falconbridge produced approximately 700 metric tons of cobalt from nickel ores at its Sudbury, Ontario, operations. In addition, 700 metric tons of cobalt was produced from custom feed smelting.⁷ Falconbridge also researched the pyrometallurgical treatment of cobalt-bearing scrap with the goal of increasing its custom feed business. Cobalt-containing nickel-copper matte from Sudbury was refined at the Falconbridge Nikkelverk refinery in Norway.

Inco produced cobalt oxide at its Thompson, Manitoba, refinery and cobalt cathode at its Port Colborne refinery. Feed materials for the two refineries originated from nickel mines in Thompson, Manitoba, and Sudbury, Ontario, respectively. Inco's production of refined cobalt was essentially the same as production during the previous year. The company produced 1,385 metric tons of cobalt in 1991 as compared with 1,380 metric tons in 1990.⁸ Inco's 1991 cobalt deliveries, including cobalt contained in alloys and engineered products, decreased 4% from deliveries in 1990 to 1,393 metric tons.⁹

In December, Inco signed an agreement with Le Bureau de Recherches Géologiques et Minières (BRGM) of France to evaluate the feasibility of developing nickel-cobalt laterites in New Caledonia (see New Caledonia section of this report).

Sherritt Gordon refined cobalt-containing materials from Canada and elsewhere at its nickel-cobalt refinery at

Fort Saskatchewan, Alberta. Production in 1990 was limited by a lack of nickel-cobalt feed. In April 1991, Sherritt reportedly was forced to reduce allocations to U.S. consumers because of the feedstock shortage. By May, Sherritt had secured a long-term source of feed and was able to operate its refinery at close to capacity during the second half of the year. As a result, Sherritt's production of cobalt metal powder in 1991 increased 19% to 821 metric tons.¹⁰

Although Sherritt does not disclose feed sources, industry analysts believed that the new feed included nickel-cobalt sulfides from Cuba's Moa Bay refinery. The sulfides, containing about 55% nickel and 5% cobalt, began appearing in Canadian import statistics in April 1991 under the trade category "nickel oxide sinters and other intermediate products of nickel metallurgy." Canada's other two nickel producers denied receiving Cuban feed. The source of the feed is significant because the United States has a trade embargo on materials originating in Cuba, which would affect nickel and cobalt produced from Cuban feedstock. By summer, Sherritt was reported to have withdrawn from the U.S. market.

Sherritt developed a proprietary process to refine the new feed, which was relatively rich in cobalt. Adaptations to the refinery began in 1991 and were expected to be completed by mid-1992, raising the refinery's cobalt capacity to approximately 1,350 metric tons per year (3 million pounds per year). Sherritt researchers also worked on the development and marketing of value-added materials, including extra-fine cobalt powder for the cemented carbide industry.

Cuba.—Cuba produces nickel-cobalt sulfides at its Moa Bay plant and nickel-cobalt oxide and oxide sinter at its Nicaro and Punta Gorda plants. All three plants use lateritic ore as their feedstock. The nickel-cobalt sulfides contain a greater percent of cobalt than the oxide and sinter, roughly 5% as compared with about 1%. Historically, all of the nickel-cobalt sulfides were refined at the Orsk nickel refinery in the southern Ural

mountains in the U.S.S.R. In 1991, Cuba began sending some of the sulfides to Canada.

Finland.—In October, Outokumpu Metals and Resources Oy and Mooney Chemicals, Inc., a U.S. cobalt chemical processor, merged their chemical businesses into a newly incorporated Delaware holding company named OM Group Inc. OM Group will produce a wide range of cobalt and nickel products, including cobalt metal powders, inorganic cobalt salts, and cobalt carboxylates. The company will operate from three locations: the Outokumpu cobalt refinery in Kokkola, Finland; the Vasset S.A. chemical processing plant in Paris, France; and the Mooney Chemicals processing plant in Franklin, PA. Vasset, a producer of cobalt carboxylates, was purchased by Outokumpu in 1990. At yearend, ownership of OM Group was divided as follows: 49% held by a consortium of Finnish companies (Nova Insurance, the Industrial Mutual Insurance Co., and Investa Oy), 47% held by Outokumpu, and 4% held by Mooney.

Outokumpu produced 1,503 metric tons of cobalt in powders and salts in 1991, a 16% increase over production in 1990.¹¹ The total production of cobalt in cobalt products by OM Group companies during 1991 was 2,115 metric tons.¹²

Japan.—Sumitomo produced electrolytic cobalt, cobalt oxide, cobalt sulfate, and other cobalt salts as a byproduct of nickel production at its Niihama Nickel Refinery in Ehime Prefecture.

According to Japan's Ministry of International Trade and Industry (MITI),¹³ 1991 Japanese reported cobalt consumption was relatively unchanged at 3,015 metric tons, as compared with 2,994 metric tons in 1990. With the exception of a 6% increase in cobalt used to make hard metal tools, cobalt consumption in all industry sectors was basically the same as consumption in 1990. In 1991, reported consumption by industry was as follows: 416 metric tons

in catalysts, 365 metric tons in hard metal tools, 631 metric tons in magnetic materials, 896 metric tons in special steels, and 707 metric tons in other uses. Total Japanese cobalt consumption was estimated to be about 4,500 metric tons. The MITI statistics do not include cobalt use in magnetic tapes—estimated at 900 to 1,000 metric tons per year of cobalt sulfate, welding materials, or diamond tools. Japanese demand for cobalt was met primarily from imports, which increased almost 50% in 1991 to 6,674 metric tons.

During 1991, the Japanese built up significant inventories of cobalt to avoid potential shortages resulting from tight market conditions.¹⁴ As compared with purchases in 1990, Japanese buyers purchased 23% more cobalt from producers and increased their purchases from the free market more than 300%. Total imports of cobalt metal and metal powder were about 6,700 metric tons. Domestic production from Sumitomo was 185 metric tons. Assuming a domestic consumption of 4,400 to 4,600 metric tons and a 300-metric-ton inventory drawdown to cover a supply deficit during the fourth quarter of 1990, roughly 2,000 metric tons of cobalt would have accumulated as inventory. The yearend inventory was larger than expected because of a slowdown in the Japanese economy beginning in the second quarter of 1991, increased use of cobalt scrap, and forward buying by consumers in early 1991. The inventory was expected to be drawn down during 1992. The long-term effects of tight cobalt supplies and high prices were projected as reduced consumption and substitution of cobalt-containing products. For example, ongoing decreases in production of samarium-cobalt and Alnico magnets were expected to continue.

New Caledonia.—In December, Inco Ltd. of Canada signed an agreement in principle with BRGM of France to investigate the feasibility of developing lateritic nickel-cobalt resources in southern New Caledonia. Under the agreement, Inco would purchase Société de Promotions de Mines (Sopromines),

the BRGM subsidiary that holds mining titles to the deposits. Inco would also buy patents and technical expertise on the processing of nickel oxide ores owned or developed by BRGM. These purchases were subject to approval by the French Government. Also considered was the formation of a joint venture between Inco and BRGM, in which Inco would have the majority interest. The feasibility study was expected to take several years, after which a decision would be made on whether to proceed with mining.

Norway.—The Falconbridge Nikkelverk refinery produced a record 1,983 metric tons of cobalt cathode in 1991, an 8% increase from the 1,830 metric tons produced in 1990.¹⁵ Feedstock for the refinery was in the form of matte from company operations in Sudbury, Canada; BCL Ltd. in Botswana; and Norilsk in the U.S.S.R.

Philippines.—During the year, the Philippine Nickel Co. continued rehabilitation of the idled Nonoc Mining and Industrial Corp. nickel production facility and sought financing for the project.

South Africa, Republic of.—Cobalt was produced as a byproduct of the Republic of South Africa's platinum industry. Refined cobalt was produced by two companies: Rustenburg Base Metal Refiners Pty. Ltd. produced cobalt sulfate, and Impala Platinum Ltd. produced cobalt metal powder. A third company, Western Platinum Ltd., produced nickel sulfate containing minor amounts of cobalt.

South Africa's Minerals Bureau reported cobalt production, domestic sales, and exports for the years 1986-90.¹⁶ The refinery production figures in table 15 have been revised to include these reported figures. The breakdown between cobalt sulfate and metal powder production was estimated as 70% sulfate and 30% powder, based on the capacities of the two refineries. Mine production estimates in table 14 were also revised. Most of the cobalt produced in the

Republic of South Africa is exported. In 1990, 88% (219 metric tons) of the 249 metric tons produced was exported, and the remaining 12% was sold domestically. Cobalt production was expected to increase in the future as a result of increases in platinum mine production.

Uganda.—BRGM completed a prefeasibility study on the recovery of cobalt from concentrates stockpiled at the Kilembe copper mines near Kasese in western Uganda. The study investigated the viability of extracting the cobalt by bioleaching methods. Previous studies estimated that more than 1 million metric tons of cobaltiferous pyrite concentrates with an average grade of 1.2% cobalt was stockpiled during copper mining and concentrating operations that ceased in 1982. In October, BRGM and United Kingdom-based Barclays Metals proposed setting up a joint venture with the Ugandan Government to prepare a detailed feasibility study, including resource evaluation and pilot plant tests, followed by the construction of a full-scale processing plant.

Venezuela.—Corporacion Federal de Minas (Cofeminas)—a joint-venture between Jordev Resources Inc., of Vancouver, British Columbia, and Corporacion de Caracas of Venezuela—secured exploration and mining rights and completed a prefeasibility study on the Loma de Hierro deposit. Loma de Hierro is a lateritic nickel deposit south of Caracas reported to contain 38.5 million metric tons of ore, grading 1.55% nickel and 0.05% cobalt.

Zaire.—Gécamines remained the world's largest cobalt producer, providing almost 35% of estimated world refinery production. The company's cobalt production decreased 18% in 1991, at least partly because of the loss of concentrates following the September 1990 cave-in at the Kamoto underground mine. The Kamoto Mine, in Gécamines Western Group near the town of Kolwezi,

is the company's largest underground copper-cobalt mine. Prior to the collapse, the mine had been a significant source of cobalt because of its high output levels and the high cobalt content of its ores. Rehabilitation of the mine has taken longer than anticipated, causing delays in restoring production to former levels. During the year, Gécamines offset some of the loss of cobalt from the Kamoto Mine by reprocessing stockpiled cobalt hydrates. The hydrates had been precipitated from Gécamines' hydrometallurgical plants' cobalt leach circuits during periods of oversupply and stockpiled for later use.

Gécamines' operations were further hampered by Zaire's declining economic condition, a continuing political stalemate, and increased social unrest. On September 23, rioting and looting by soldiers and civilians spread from Kinshasa to other urban areas, including towns in the copper-cobalt mining area. Belgian and French troops were sent to Zaire on September 24th to protect foreign residents and to evacuate those that wanted to leave. Thousands of foreign nationals were reported to have left the country. Gécamines' offices in Kolwezi were demolished, and mining operations there were interrupted for several days. Violence recurred in late October in Kinshasa and in the Copperbelt, where production was again suspended. While no intentional damage occurred to the mines or refineries during the looting, the facilities suffered from the lack of proper maintenance during interruptions in production.

Zaire's political situation caused Western governments and international financial institutions to withdraw all financial aid, including that to state-owned Gécamines. By yearend, the company was unable to fulfill its delivery quotas for 1991. In December, Gécamines and ZCCM revised their 1992 producer price for cobalt, with the hope that the added income would help to increase future production. Gécamines continued seeking financing and estimated that \$300 to \$400 million would be needed to rehabilitate the Kamoto Mine, repair Gécamines facilities, and bring

copper and cobalt production back to former levels. The company hoped to maintain production at 8,000 to 9,000 metric tons in 1992, but industry analysts cautioned that production could be lower than 1991 levels.

The project with Techpro Mining and Metallurgy of the United Kingdom for the recovery of cobalt and copper from leach residues was delayed and downsized. Originally, Techpro was to construct a horizontal belt filter and two flotation columns at the Shituru plant and a horizontal belt filter at the Luilu plant. Progress on the project was slowed by a delay by Gécamines in providing downpayment to Techpro. In addition, the project scope was reduced to construction of a horizontal belt filter at Shituru.

Zambia.—Zambia had its first multiparty elections since its independence in 1964. The newly elected President replaced ZCCM's top management and began an examination of company financial records for alleged corruption. The President was also reported to be considering various means of encouraging foreign investment, including privatization of some state-owned companies. ZCCM produced 4,817 metric tons of refined cobalt metal between January and December 1991.¹⁷ This production was basically the same as the 4,844 metric tons produced in calendar year 1990.

Zimbabwe.—Minor amounts of impure cobalt oxide were produced in Zimbabwe as a byproduct of nickel mining and refining. The cobalt oxide was exported to be refined. (See tables 14 and 15.)

Current Research

The U.S. Bureau of Mines researched the recovery of individual metals from mixed superalloy scrap.¹⁸ A combined pyrometallurgical and hydrometallurgical process was used. The superalloy scrap was melted, then sulfur was added to form a matte. The matte was then granulated and ground to an appropriate

particle size for leaching with a chloride leach solution. Molybdenum was recovered from the leach solution by solvent extraction. Chromium and iron were recovered by precipitation. The remaining purified leach solution contained the cobalt and nickel, which could be recovered by a commercial solvent extraction-electrowinning process.

The CDI of Wickford, Essex, United Kingdom, published abstracts on cobalt research, articles on selected cobalt uses, and annual and semiannual data on cobalt production by institute members in quarterly issues of Cobalt News.

OUTLOOK

The future cobalt market will depend on the balance between several supply and demand factors. Even at reduced production levels, Zaire is still the world's largest cobalt producer, and the quantity and quality of cobalt it produces will continue to be important factors in world supply. Political and economic conditions in Zaire have not yet been resolved. Gécamines' ability to bring its production back to former levels and rebuild stocks of cobalt metal both in Zaire and in consuming countries will be determining factors in the cobalt market. Since the collapse of the Kamoto mine, a significant portion of Gécamines' cobalt production has been from the reprocessing of stockpiled cobalt hydrates. Steady production of cobalt in the future will depend on Gécamines' success in rehabilitating the Kamoto Mine and improving production at its other copper-cobalt mines before stocks of cobalt hydrates are depleted. These improvements will depend on the company's ability to acquire financing.

In 1991, cobalt from the U.S.S.R. contributed significantly to alleviate the tight supply situation. Supplies to Western markets included cobalt from strategic stockpiles and cobalt produced in the U.S.S.R. The amount of cobalt remaining in the stockpiles is not known. In terms of domestically produced cobalt, Russian production is expected to decrease in 1992, and some of the cobalt will be reserved for domestic use. An

estimated 1,000 metric tons of Russian-produced cobalt may be available for export in 1992. However, cobalt exports are controlled by the state, which had not granted export licenses to producers by mid-1992.

Sales of cobalt by the U.S. Government could provide a steady addition to supply for several years. During 1991, the DLA proposed reducing the size of the NDS. Adoption of the proposed stockpile goal for cobalt would result in excess cobalt available for disposal. Before sales of excess materials could occur, Congress must approve the proposed goals and pass legislative authority for the disposals. The DLA proposal recommended sales at a rate of 1,360 metric tons per year.

In the longer term, current high prices give added incentive to potential new producers. The Government of Uganda, in conjunction with BRGM, and MIM of Australia are each investigating the production of cobalt by bioleaching byproduct cobalt from former or present-day copper production. Blackbird Metals continues with its plans to build a U.S. cobalt refinery, although it has decided to postpone the purchase and reopening of the Blackbird Mine in Idaho and is considering other feed sources. Potential new producers such as Knox Nickel in Maine, or former producers such as Nonoc in the Philippines, would produce cobalt as a byproduct of nickel, and their success will depend to a large extent on the nickel market.

In addition to the quantity of future cobalt supply, quality is also a concern. Not all cobalt metal available is suitable for all applications. Zaire and Zambia each produce several grades of refined cobalt. Zaire's projected 1992 production includes cobalt contained in matte and alliage blanc (an alloy of copper, cobalt, and iron), which are intermediate products that require further refining. Russian cobalt ingots are not as high grade as cobalt from other sources and must be cut to a smaller size before they can be used by some consumers. NDS cobalt to be offered for sale will be cobalt purchased prior to 1980, when purchase specifications were not as stringent as

those in effect today. This cobalt has been identified as unsuitable for the most demanding uses, in particular, vacuum-melted superalloys.

On the demand side, increases in consumption will depend on the economies of the major consuming countries. Continued high prices are likely to result in increased use of cobalt scrap and substitution where possible. Future demand could be negatively impacted if engineers choose to avoid cobalt in products now under development—both price and future availability are important in materials selection.

Overall Western World cobalt supply and demand are currently close to being in balance. However, a decrease in Western World production without added cobalt from non-Western producers or strategic stockpiles, or an increase in consumption without increased supply, could upset the balance. In addition to overall supply and demand, the supply-demand balance of higher quality grades of cobalt also bears watching. Once producers rebuild their stocks, short-term disruptions in supply can be reduced. Cobalt prices are expected to decrease to more typical levels when increased supply brings the market into a more comfortable balance.

¹Masson, C. Cobalt Specifications, a Producer's View. Pres. at Cobalt Development Inst. seminar, Boston, MA, Oct. 25, 1988; available from the Cobalt Development Inst., Suite 22, Riverside House, Lower Southend Road, Wickford, Essex, SS11 8BB, United Kingdom.

²Willard, D. G., and D. I. Bleiwas. Cobalt Availability—A Minerals Availability Appraisal. BuMines IC 9286, 1991, 35 pp.

³Federal Register. The President. Executive Order 12769 of July 10, 1991—Implementation of Section 311(a) of the Comprehensive Anti-Apartheid Act. V. 56, No. 134, July 12, 1991, p. 31855.

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⁴Black Hawk Mining Inc. 1991 Annual Report, 20 pp.

⁵The Cobalt Development Institute (Wickford, Essex, United Kingdom). Statistics and Statistical Review of 1991. Cobalt News, v. 2, Apr. 1992, pp. 9-10.

⁶Metal Bulletin (London). MIM Contemplates Cobalt Production. No. 7693, June 29, 1992, p. 9.

⁷Falconbridge Ltd. 1991 Annual Report, 24 pp.

⁸Work cited in footnote 5.

⁹Inco Ltd. 1991 Annual Report, 54 pp.

¹⁰Sherritt Gordon Ltd. 1991 Annual Report, 36 pp.

¹¹Work cited in footnote 5.

¹²Outokumpu Oy. 1991 Annual Report, 73 pp.

¹³Robjohns, N. (ed.). Cobalt: Japanese Market in 1991 and Outlook for 1992. Roskill's Letter From Japan, No. 192, Apr. 1992, pp. 14-15.

¹⁴Miyamura, K. From the Viewpoint of Japanese Cobalt Consumer. Pres. at Cobalt at the Crossroads Conference, Herndon, VA, June 23-24, 1992; available from Intertech Conferences, 170 U.S. Route One, Portland, ME 04105.

¹⁵Work cited in footnote 5.

¹⁶Odendaal, N. J. Cobalt. Ch. in South Africa's Mineral Industry 1990. Republic of South Africa, Department of Mineral and Energy Affairs, Minerals Bureau, 8th ed., 1991, pp. 79-82.

¹⁷Work cited in footnote 5.

¹⁸Hendley, G. L., and D. L. Davis. Recovery of Critical Metals From Superalloy Scrap by Matte Smelting and Hydrometallurgical Processing. BuMines RI 9390, 1991, 11 pp.

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The Economics of Cobalt, 7th ed., 1992.

TABLE 1
WORLD PRODUCERS OF REFINED COBALT¹

Country	Company	Cobalt products
Albania	Government-owned	Oxide.
Brazil	Companhia Niquel Tocantins	Cathode.
Canada	Inco Ltd.	Cathode, oxide.
Do.	Sherritt Gordon Ltd.	Metal powder, briquettes.
China	Government-owned	NA.
Finland	Outokumpu Oy	Metal powder, oxide, salts.
France	Eramet-SLN	Chloride.
Japan	Sumitomo Metal Mining Co. Ltd.	Cathode, oxide, salts.
Norway	Falconbridge Ltd.	Cathode.
South Africa, Republic of	Impala Platinum Ltd.	Metal powder.
Do.	Rustenberg Base Metal Refiners Pty. Ltd.	Sulfate.
U.S.S.R.	Government-owned	Ingot, cathode, oxide, salts.
Zaire	La Générale des Carrières et des Mines.	Cathode, granules.
Zambia	Zambia Consolidated Copper Mines Ltd.	Cathode, crushed bar.

NA Not available.

¹Companies with production during 1991.

TABLE 2
WORLD PRODUCERS OF INTERMEDIATE COBALT PRODUCTS¹

Country	Company	Cobalt-containing products
Australia	Queensland Nickel Pty. Ltd.	Cobalt sulfide.
Do.	Western Mining Corp.	Nickel-cobalt sulfide.
Do.	Pacific Smelting and Mining Co. Ltd.	Impure cobalt oxide.
Botswana	BCL Ltd.	Nickel-copper matte.
Cuba	Union de Empresas del Niquel	Nickel-cobalt oxide, ² nickel-cobalt sulfide.
Morocco	Compagnie de Tifnout Tiranimine	Cobalt concentrate.
New Caledonia	Société Metallurgique le Nickel	Nickel matte.
South Africa, Republic of	Western Platinum Ltd.	Nickel sulfate, nickel matte.
Zimbabwe	Bindura Nickel Corp. Ltd.	Cobalt-nickel hydroxide.
Do.	Rio Tinto (Zimbabwe) Ltd.	Do.

¹Companies with production during 1991; excludes companies producing refined cobalt.

²Cobalt may not be recovered.

TABLE 3
SALIENT COBALT STATISTICS

(Metric tons cobalt content unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Consumption:					
Reported	'6,666	'7,308	'7,172	'7,512	7,238
Apparent	7,986	7,824	7,164	'7,635	7,786
Imports for consumption	8,832	7,051	5,793	6,529	6,924
Stocks, December 31 ¹	2,043	1,766	'1,456	'1,853	1,622
Price: Metal, per pound ²	\$6.56	\$7.09	\$7.64	\$10.09	\$16.92
World: Production					
Mine	'41,245	'43,819	'36,000	'35,709	'26,583
Refinery	'27,995	'26,407	'25,181	'25,316	'23,922

¹Estimated. ²Revised.

¹Stocks held by consumers and chemical processors.

²Market price based on weighted average of Metals Week prices.

TABLE 4
U.S. REPORTED CONSUMPTION OF COBALT,¹ BY END USE

(Metric tons, cobalt content)

End use	1988	1989	1990	1991
Steel:				
Full-alloy	W	W	W	W
High-strength, low-alloy	W	—	—	—
Stainless and heat-resisting	26	74	41	51
Tool	180	219	123	W
Superalloys	'2,865	'2,860	'3,345	3,066
Alloys (excluding alloy steels and superalloys):				
Cutting and wear-resistant materials ²	'522	'538	'541	523
Magnetic alloys	'878	'870	'710	713
Nonferrous alloys	'64	27	31	32
Welding materials (structural and hard-facing) ³	'206	'136	'180	135
Other alloys	'86	'52	'74	62
Mill products made from metal powder	W	W	W	W
Drier in paint or related usage	892	718	'751	781
Miscellaneous and unspecified ⁴	'1,590	'1,680	'1,717	1,876
Total⁶	'7,308	'7,172	'7,512	7,238

¹Revised. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

²Includes estimates.

³Includes diamond bit matrices, cemented and sintered carbides, and cast carbide dies or parts.

⁴Includes wear-resistant alloys.

⁵Data not comparable with those prior to 1990 because of a change in reporting method.

⁶Includes catalysts, feed or nutritive additive, glass decolorizer, ground coat frit, pigments, and data indicated by symbol "W."

Data may not add to totals shown because of independent rounding.

TABLE 5
U.S. REPORTED CONSUMPTION OF COBALT,¹ BY FORM

(Metric tons, cobalt content)

	1987	1988	1989	1990	1991
Chemical compounds (organic and inorganic) ²	¹ 1,812	² 2,032	² 2,081	² 2,192	2,137
Metal	³ 3,826	⁴ 4,256	³ 3,907	⁴ 4,095	3,524
Purchased scrap	¹ 1,028	1,018	1,184	1,225	1,578
Total³	⁶6,666	⁷7,308	⁷7,172	⁷7,512	7,238

¹Revised.

²Includes estimates.

³Includes oxides.

⁴Data may not add to totals shown because of independent rounding.

TABLE 6
U.S. REPORTED STOCKS OF COBALT MATERIALS,¹ DECEMBER 31

(Metric tons, cobalt content)

	1987	1988	1989	1990	1991
Chemical compounds (organic and inorganic) other than oxide	282	249	¹ 2394	¹ 2379	² 362
Metal	1,486	1,278	860	¹ 1,342	1,072
Oxide	105	76	(¹)	(¹)	(¹)
Scrap	171	162	² 202	132	189
Total⁴	2,043	1,766	¹1,456	¹1,853	1,622

¹Revised.

²Stocks reported by cobalt processors and consumers; includes estimates.

³Includes oxide.

⁴Included with "Chemical compounds."

⁵Data may not add to totals shown because of independent rounding.

TABLE 7
YEAREND PRICES OF COBALT MATERIALS¹

(Dollars per pound)

Material	1987 ²	1988	1989	1990	1991
Cobalt metal:					
Cathode or granules (shot) ^{3 4}	7.50	8.40	8.40	8.40	11.00
Fine powder (less than 1.6 micrometers) ⁵	16.85	17.75	17.75	22.11	31.67
Powder (300-mesh, 400-mesh, 100-mesh)	13.84	14.74	14.71	18.63	29.46
S-grade powder (minus 48-mesh)	7.75	8.65	⁶ 8.65	⁶ 8.65	⁷ 11.90
Cobalt oxide:					
Ceramic-grade (70% to 71% cobalt)	8.80	9.70	9.42	11.14	18.94
Ceramic-grade (72% to 73% cobalt)	9.04	9.94	9.67	11.44	19.44
Metallurgical-grade (76% cobalt)	9.41	10.31	10.06	11.67	19.69

¹Prices for 1987-88 are from Metals Week; 1989-91 prices are list prices from African Metals Corp., unless otherwise noted.

²Represents prices as of Jan. 21, 1988.

³See table 3 for cathode market price.

⁴250-kilogram drums.

⁵50-kilogram drums.

⁶Sherritt Gordon Ltd. list price.

⁷Metals Week.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF COBALT, BY FORM

(Metric tons unless otherwise specified)

Form	1989	1990	1991
Metal:¹			
Gross weight	5,444	² 6,027	6,375
Cobalt content*	5,444	² 6,027	6,375
Value	\$91,960	² \$106,902	\$157,711
Oxides and hydroxides:			
Gross weight	380	488	583
Cobalt content*	273	351	420
Value	\$6,598	\$8,539	\$12,941
Other forms:			
Acetates:			
Gross weight	77	120	33
Cobalt content*	19	29	8
Value	\$492	\$866	\$309
Carbonates:			
Gross weight	11	36	53
Cobalt content*	5	16	24
Value	\$118	\$594	\$776
Chlorides:			
Gross weight	11	19	12
Cobalt content*	3	5	3
Value	\$56	\$103	\$101
Sulfates:			
Gross weight	182	372	350
Cobalt content*	49	101	95
Value	\$760	\$1,664	\$2,295
Total:³			
Gross weight	6,105	² 7,062	7,406
Cobalt content*	5,793	² 6,529	6,924
Value	\$99,984	² \$118,668	\$174,134

¹Estimated.

²Unwrought cobalt, excluding alloys.

³Includes 108 metric tons valued at \$1,747,104, shipped to the National Defense Stockpile.

⁴Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census; minor adjustments by the U.S. Bureau of Mines.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF COBALT, BY COUNTRY

Country of origin	Metal ¹			Oxides and hydroxides			Other forms ³			Total ⁴		
	Gross weight (metric tons)	Cobalt content ² (metric tons)	Value (thousands)	Gross weight (metric tons)	Cobalt content ² (metric tons)	Value (thousands)	Gross weight (metric tons)	Cobalt content ² (metric tons)	Value (thousands)	Gross weight (metric tons)	Cobalt content ² (metric tons)	Value (thousands)
1990:												
Belgium	175	175	\$4,042	242	174	\$4,078	130	39	\$926	547	388	\$9,047
Brazil	39	39	660	—	—	—	—	—	—	39	39	660
Canada	1,284	1,284	21,551	17	12	304	11	3	21	1,312	1,299	21,876
Finland	54	54	2,050	143	103	2,559	83	24	511	281	181	5,121
France	14	14	756	8	6	364	—	—	—	22	19	1,120
Germany, Federal Republic of	90	90	2,500	(⁵)	(⁵)	15	—	—	—	90	90	2,515
Japan	22	22	584	(⁵)	(⁵)	1	—	—	—	22	22	586
Norway	⁶ 844	⁶ 844	⁶ 14,096	—	—	—	—	—	—	⁶ 844	⁶ 844	⁶ 14,096
South Africa, Republic of	2	2	51	24	17	366	204	55	939	230	74	1,357
United Kingdom	—	—	—	48	35	770	118	29	829	166	64	1,599
U.S.S.R.	42	42	832	—	—	—	—	—	—	42	42	832
Zaire	1,834	1,834	33,754	—	—	—	—	—	—	1,834	1,834	33,754
Zambia	1,611	1,611	25,523	—	—	—	—	—	—	1,611	1,611	25,523
Other	18	18	502	5	4	80	—	—	—	23	21	582
Total ⁴	<u>⁶6,027</u>	<u>⁶6,027</u>	<u>⁶106,902</u>	<u>488</u>	<u>351</u>	<u>8,539</u>	<u>547</u>	<u>150</u>	<u>3,227</u>	<u>⁶7,062</u>	<u>⁶6,529</u>	<u>⁶118,668</u>
1991:												
Belgium	119	119	4,316	300	216	6,773	159	43	1,120	578	378	12,208
Brazil	52	52	1,556	—	—	—	—	—	—	52	52	1,556
Canada	1,027	1,027	24,368	10	7	222	5	2	16	1,042	1,037	24,606
Finland	149	149	5,836	150	108	3,266	163	52	1,579	462	309	10,681
France	39	39	1,486	4	3	177	—	—	—	43	42	1,663
Germany, Federal Republic of	88	88	2,942	1	1	24	15	4	104	103	92	3,070
Japan	1	1	32	(⁵)	(⁵)	8	—	—	—	2	2	40
Norway	881	881	23,576	—	—	—	—	—	—	881	881	23,576
South Africa, Republic of	51	51	1,189	—	—	—	104	28	650	155	79	1,839
United Kingdom	39	39	988	117	84	2,471	—	—	—	157	124	3,459
U.S.S.R.	285	285	7,128	—	—	—	—	—	—	285	285	7,128
Zaire	1,748	1,748	42,501	—	—	—	—	—	—	1,748	1,748	42,501
Zambia	1,895	1,895	41,765	—	—	—	—	—	—	1,895	1,895	41,765
Other	(⁵)	(⁵)	30	—	—	—	2	1	13	3	1	43
Total ⁴	<u>6,375</u>	<u>6,375</u>	<u>157,711</u>	<u>583</u>	<u>420</u>	<u>12,941</u>	<u>448</u>	<u>130</u>	<u>3,482</u>	<u>7,406</u>	<u>6,924</u>	<u>174,134</u>

¹Unwrought cobalt, excluding alloys and waste and scrap.

²Estimated from gross weights.

³Cobalt sulfates, cobalt chlorides, cobalt carbonates, and cobalt acetates.

⁴Data may not add to totals shown because of independent rounding.

⁵Less than 1/2 unit.

⁶Includes 108 metric tons valued at \$1,747,104 shipped to the National Defense Stockpile.

Source: Bureau of the Census.

TABLE 10
U.S. IMPORTS FOR CONSUMPTION OF ADDITIONAL COBALT
MATERIALS, BY COUNTRY, 1991

Country of origin	Unwrought cobalt alloys		Other cobalt: matte, waste and scrap ²		Wrought cobalt and cobalt articles	
	Gross weight (metric tons)	Value ¹ (thousands)	Gross weight (metric tons)	Value ¹ (thousands)	Gross weight (metric tons)	Value ¹ (thousands)
Belgium	1	\$21	—	—	(³)	\$2
Canada	3	163	35	\$315	5	134
France	17	635	29	368	6	102
Germany, Federal Republic of	7	517	54	535	28	1,100
Japan	52	1,658	23	245	28	3,093
Mexico	—	—	19	56	—	—
Sweden	11	334	48	404	(³)	3
Switzerland	1	75	—	—	(³)	40
United Kingdom	3	64	139	1,594	37	972
Other	4	128	25	404	2	57
Total ⁴	99	3,594	370	3,922	105	5,503

¹Customs value.

²Includes other intermediate products of cobalt metallurgy; may include other cobalt-bearing materials from which cobalt is extracted or from which cobalt-containing chemical compounds are manufactured.

³Less than 1/2 unit.

⁴Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 11
U.S. IMPORT DUTIES FOR COBALT-CONTAINING MATERIALS, EFFECTIVE JANUARY 1, 1991

Item	HTS No.	Most favored nation (MFN)	Non-MFN	Special	
				CA ¹	A, E, IL ²
Chemical compounds:					
Cobalt acetates	2915.23.00	4.2%	30%	1.6%	Free (A, E, IL).
Cobalt carbonates	2836.99.10	4.2%	30%	Free	Do.
Cobalt chlorides	2827.34.00	4.2%	30%	1.6%	Do.
Cobalt oxides and hydroxides	2822.00.00	2.6 cents per kilogram	44 cents per kilogram	1 cent per kilogram	Do.
Cobalt sulfates	2833.29.10	1.4%	6.5%	0.5%	Do.
Cobalt matte, waste and scrap	8105.10.90	Free	Free	XX	XX.
Cobalt ores and concentrates	2605.00.00	Free	Free	XX	XX.
Unwrought cobalt alloys	8105.10.30	5.5%	45%	2.2%	Free (E, IL).
Unwrought cobalt, other	8105.10.60	Free	Free	XX	XX.
Wrought cobalt and cobalt articles	8105.90.00	5.5%	45%	2.2%	Free (A, E, IL).

XX Not applicable.

¹United States-Canada Free-Trade Agreement.

²A, Generalized System of Preferences; E, Caribbean Basin Economic Recovery Act; IL, United States-Israel Free-Trade Area.

³Duty on unwrought alloys of cobalt, containing by weight, 76% or more but less than 99% cobalt, originating in Canada temporarily suspended (on or before Dec. 31, 1993).

Source: U.S. International Trade Commission, Harmonized Tariff Schedule of the United States (1991), USITC Publication 2333.

TABLE 12
U.S. EXPORTS OF COBALT IN 1991, BY COUNTRY¹

Country of destination	Metal ²		Oxides and hydroxides		Acetates		Chlorides		Total content ⁴ (metric tons)	Total value ³ (thousands)
	Gross weight (metric tons)	Value ³ (thousands)								
Argentina	3	\$90	25	\$533	—	—	—	—	21	\$623
Australia	20	252	30	623	—	—	—	—	42	875
Austria	21	57	(⁵)	3	—	—	—	—	21	59
Belgium	9	124	—	—	—	—	—	—	9	124
Brazil	18	679	36	811	43	\$374	24	\$176	60	2,040
Canada	146	4,281	20	236	17	155	167	852	207	5,524
Costa Rica	—	—	76	119	—	—	—	—	55	119
Dominican Republic	—	—	91	15	—	—	—	—	65	15
Ecuador	(⁵)	6	45	167	—	—	—	—	33	173
France	14	407	19	166	—	—	—	—	28	573
Germany	19	1,107	27	166	—	—	—	—	38	1,273
Guatemala	—	—	17	24	—	—	—	—	12	24
Italy	5	119	133	2,002	32	325	6	41	110	2,487
Japan	124	2,216	60	1,087	—	—	—	—	167	3,303
Korea, Republic of	4	105	49	925	35	328	37	110	57	1,468
Mexico	8	283	221	1,894	131	941	5	33	200	3,150
Netherlands	52	1,502	29	128	10	57	—	—	75	1,688
Panama	—	—	95	138	—	—	—	—	68	138
Taiwan	(⁵)	3	14	239	254	2,065	10	84	73	2,391
Turkey	(⁵)	5	—	—	20	142	—	—	5	147
United Kingdom	76	1,915	9	74	18	39	—	—	87	2,027
Venezuela	(⁵)	3	24	518	1	11	—	—	17	532
Other	23	809	83	754	8	66	3	69	85	1,698
Total⁶	543	13,963	1,102	10,623	570	4,503	252	1,363	1,536	30,451

¹In addition to the materials listed, the United States exported cobalt ores and concentrates and wrought cobalt and cobalt articles.

²Includes unwrought cobalt, powders, waste and scrap, and mattes and other intermediate products of cobalt metallurgy.

³Customs value.

⁴Estimated from gross weights.

⁵Less than 1/2 unit.

⁶Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 13
WORLD ANNUAL COBALT
PRODUCTION CAPACITY,
DECEMBER 31, 1991

(Metric tons, cobalt content)

Country	Refinery capacity
Brazil	300
Canada	3,000
Finland ¹	1,800
France ²	600
Japan ^{1,3}	2,800
Norway	2,200
South Africa, Republic of ⁴	750
U.S.S.R.* ⁴	6,600
United States ⁵	900
Zaire	18,000
Zambia	5,000
Total⁶	41,950

*Estimated. Revised.

¹Includes salts.

²Cobalt chloride.

³Includes standby capacity of 1,200 metric tons.

⁴Based on estimated production.

⁵Standby capacity.

⁶Does not include Albania or China.

TABLE 14
COBALT: WORLD MINE PRODUCTION, BY COUNTRY¹

(Metric tons, cobalt content)

Country ²	1987	1988	1989	1990	1991 ³
Albania ⁴	600	600	600	600	600
Australia ⁴	1,261	1,200	1,000	1,000	1,000
Botswana ⁵	181	291	215	205	200
Brazil ⁶	150	150	200	200	200
Canada ⁶	2,490	2,398	2,344	2,184	2,158
Cuba ⁷	1,566	1,783	1,825	1,600	1,600
Finland ⁸	190	—	—	—	—
Morocco ⁹	224	253	121	194	525
New Caledonia ¹⁰	750	800	800	800	800
South Africa, Republic of ⁶	380	300	300	350	300
U.S.S.R.*	2,800	2,850	2,850	2,400	2,200
Zaire ⁹	23,200	26,000	18,400	19,000	9,900
Zambia ⁹	7,365	7,090	7,255	7,086	7,000
Zimbabwe ¹³	88	104	90	90	100
Total	41,245	43,819	36,000	35,709	26,583

*Estimated. Revised.

¹Table includes data available through June 5, 1992. Figures represent recoverable cobalt content of ores, concentrates, or intermediate products from copper, nickel, platinum, or zinc operations. Morocco was the only country where cobalt was mined as a primary product.

²In addition to the countries listed, Bulgaria, China, the Eastern states of the Federal Republic of Germany, Indonesia, and Poland are known to produce ores that contain cobalt, but information is inadequate for reliable estimates of output levels. Other copper-, nickel-, platinum-, or zinc-producing nations may also produce ores containing cobalt as a byproduct component, but recovery is small or nil.

³Calculated from reported and estimated weight of nickeliferous ore.

⁴Figures represent quantities of cobalt contained in intermediate metallurgical products (cobalt oxide and nickel-cobalt sulfide). Cobalt content of lateritic nickel ore, nickel concentrate, and zinc concentrate was as follows, in metric tons: 1987—2,715; 1988—2,574 (estimated); 1989—2,375 (estimated); 1990—2,375 (estimated); and 1991—2,400 (estimated).

⁵Reported cobalt content of pelletized nickel-copper matte.

⁶Figures represent total cobalt content of all products derived from ores of Canadian origin, including cobalt oxides shipped to the United Kingdom for further processing and nickel-copper-cobalt mattes shipped to Norway for further processing. Actual mine production was reported as follows, in metric tons: 1987—5,490; 1988—6,234; 1989—6,167; 1990—5,470; and 1991—5,629.

⁷Reported figure.

⁸Determined from reported nickel-cobalt content of granular and powder oxide, oxide sinter, and sulfide production.

⁹Cobalt content of concentrates.

¹⁰Series represents estimated recoverable content of ores and intermediate metallurgical products exported from New Caledonia to France and Japan. The estimated cobalt content of total ores mined is as follows, in metric tons: 1987—5,800; 1988—6,000; 1989—6,000; 1990—6,000; and 1991—6,000.

¹¹In addition to concentrates, cobalt hydrates and scrap are used as feed to the refineries. Cobalt content of these materials was as follows, in metric tons: Hydrates: 1987—1,042; 1988—0; 1989—0; 1990—3,194; and 1991—5,483. Scrap: 1987—33; 1988—31; 1989—27; 1990—49; and 1991—516.

¹²Fiscal years beginning Apr. 1 of that stated. Cobalt content of ore milled was as follows, in metric tons: 1987—11,198; 1988—10,687; 1989—10,590; 1990—10,870 (revised); and 1991—10,880 (estimated).

¹³Estimated cobalt content of ore.

TABLE 15
COBALT: WORLD REFINERY PRODUCTION, BY COUNTRY AND PRODUCT¹

(Metric tons, cobalt content)

Country ²	1987	1988	1989	1990	1991 ³
Albania: Oxide ⁴	—	10	10	20	20
Brazil: Metal	—	—	³⁰	⁶⁰	60
Canada: Metal (including metal powder and oxide)	^{2,527}	^{2,356}	^{2,109}	^{2,062}	^{2,248}
China: Metal ⁵	270	270	270	³²⁵	350
Finland:					
Metal (including metal powder)	497	229	²⁹²	³³⁰	300
Salts	⁷³⁷	903	^{1,003}	⁹⁷⁰	1,203
Total	^{1,234}	1,132	1,295	1,300	^{1,503}
France: Chloride (solution)	136	176	¹⁶⁵	¹⁵⁰	150
Japan: Metal	124	109	99	199	¹⁸⁵
Norway: Metal	1,576	1,951	1,946	1,830	^{1,983}
South Africa, Republic of:					
Metal (powder) ⁶	⁸⁰	⁶⁰	⁶⁰	⁷⁰	60
Sulfate ⁶	¹⁸³	¹⁴⁶	¹³⁹	¹⁷⁹	149
Total	²⁶³	²⁰⁶	¹⁹⁹	²⁴⁹	²⁰⁹
U.S.S.R.: Unspecified ⁶	5,300	5,300	5,300	4,500	4,500
Zaire: Metal ⁴	11,871	10,026	9,311	^{9,947}	^{8,114}
Zambia: Metal ⁵	4,694	4,871	4,447	^{4,674}	4,600
Total	^{27,995}	^{26,407}	^{25,181}	^{25,316}	23,922
Of which:					
Metal	^{21,639}	^{19,872}	^{18,564}	^{19,497}	17,900
Salts	^{1,056}	^{1,235}	^{1,317}	^{1,319}	1,522
Unspecified	5,300	5,300	5,300	4,500	4,500

¹Estimated. ²Revised.

³Table includes data available through June 5, 1992. Figures represent cobalt refined from ores, concentrates, or intermediate products and do not include production of downstream products from refined cobalt.

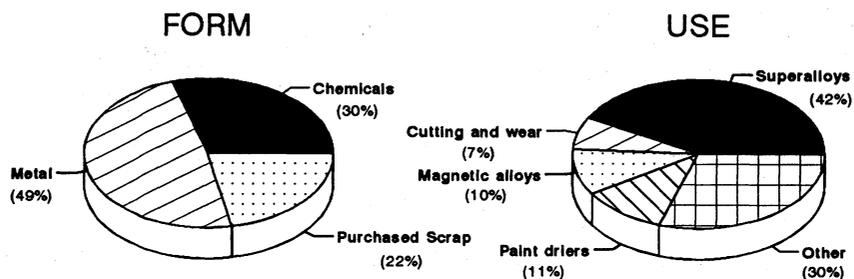
⁴In addition to the countries listed, Belgium, Czechoslovakia, and the Western states of the Federal Republic of Germany may recover cobalt from imported materials, but production is not reported, and information is inadequate to make reliable estimates of production.

⁵Reported figure.

⁶Excludes production of cobalt in white alloy and cobalt-nickel matte that would require further refining.

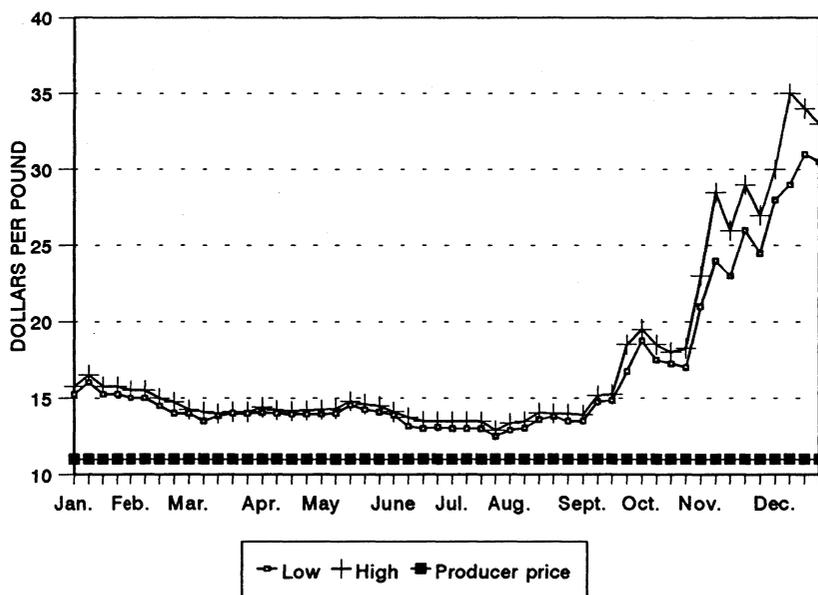
⁷Fiscal years beginning Apr. 1 of that stated.

FIGURE 1
U.S. COBALT CONSUMPTION IN 1991, BY FORM AND USE



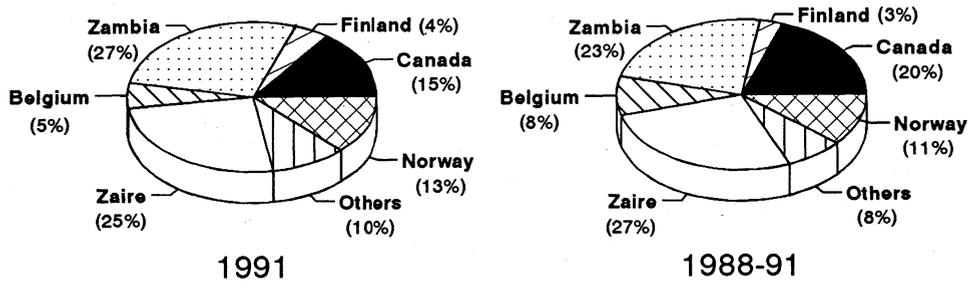
7,238 Metric tons

FIGURE 2
TIME-PRICE RELATIONSHIPS FOR COBALT IN 1991



Source: Metals Week.

FIGURE 3
U.S. COBALT IMPORTS, BY SOURCE



COLUMBIUM (NIOBIUM) AND TANTALUM

By Larry D. Cunningham

Mr. Cunningham, a physical scientist with 12 years U.S. Bureau of Mines experience, has served as the commodity specialist for columbium and tantalum since 1983. Domestic survey and trade data were prepared by Cheryl M. Mack, statistical assistant; and columbium and tantalum world production data, by country, were prepared by Audrey D. Wilkes, international data coordinator.

Columbium (Cb) is vital as an alloying element in steels and in superalloys for aircraft turbine engines and is in greatest demand in industrialized countries. Columbium is critical to the United States because of its defense-related uses in the aerospace, energy, and transportation industries. Acceptable substitutes are available for some columbium applications, but in most cases they are less desirable.

Tantalum (Ta) is used mostly in the electronics industry, mainly in capacitors, and in aerospace and transportation applications. Tantalum is also critical to the United States because of its defense-related applications in aircraft, missiles, and radio communications. Substitution for tantalum is made at either a performance or economic penalty in most applications.

Domestic columbium and tantalum resources are of low-grade and are not commercially recoverable. The last significant mining of columbium and tantalum was during the Korean conflict when increased military demand resulted in columbium and tantalum ore shortages.

The metric system is the official system of measurement of most countries. The U.S. Bureau of Mines, in an effort to provide statistical data on columbium and tantalum that are consistent with international usage, will henceforth report data in kilograms and metric tons unless otherwise noted. For comparison to previous years' data, kilograms can be converted to pounds by multiplying the published number by 2.20462, and metric tons can be converted to short tons by

multiplying the published number by 1.10231.

The United States continued to be dependent on imports of columbium and tantalum materials, with Brazil being the major source for columbium imports and Germany the major source for tantalum imports. Columbium and tantalum price quotations remained stable.

National Defense Stockpile (NDS) goals and inventoried stocks for columbium and tantalum remained the same. However, to ensure future tantalum availability to the United States, the Defense Logistics Agency (DLA) awarded a contract for purchase of the product "tantalum oxide" for the NDS.

Overall reported consumption of columbium in the form of ferrocolumbium and nickel columbium was down, with demand for columbium in superalloys up slightly. Demand for tantalum was flat, with the consumption of capacitor-grade powder on the decline.

DOMESTIC DATA COVERAGE

Domestic production data for ferrocolumbium are developed by the U.S. Bureau of Mines from the annual voluntary domestic survey for ferroalloys. Of the four operations to which a survey request was sent, two responded. Thus, ferrocolumbium production data for 1991 were incomplete at the time this report was prepared.

BACKGROUND—COLUMBIUM

Columbium and niobium are synonymous names for the chemical element with atomic number 41; columbium was the first name given, and niobium was the name officially designated by the International Union of Pure and Applied Chemistry in 1950. The metal conducts heat and electricity relatively well, has a high melting point (2,480° C), is readily fabricated, and is highly resistant to many chemical environments. Columbium exhibits superconductivity at about 9° K, a temperature still too low for most commercial applications. (Superconductivity is the virtual loss of electrical resistance that occurs at a specific material dependent temperature and results in energy conservation and more rapid operation of electrical circuits.)

Definitions, Grades, and Specifications

Columbium pentoxide (oxide) is a stable, white- to buff-colored compound that is produced in metallurgical, ceramic, and optical grades. Purity of oxide generally exceeds 99%.

Ferrocolumbium is categorized into three grades by American Society for Testing and Materials (ASTM) Specification A550: low-alloy steel grade, alloy and stainless steel grade, and high-purity grade. For all grades, the composition is approximately 65% columbium, with the balance iron; principal impurities are aluminum, silicon, and tantalum. Nickel

columbium typically contains 63% columbium, with the balance nickel. Aluminum, iron, silicon, and tantalum are the principal impurities.

Columbium carbide is available as a powder containing about 87% columbium and the balance carbon.

Columbium metal is available in many forms and shapes. Purity of unalloyed metal is usually more than 99%, with attention mainly given to iron, tantalum, and zirconium as metallic impurities and carbon, hydrogen, nitrogen, and oxygen as interstitial impurities. Alloys with hafnium, tantalum, titanium, tungsten, and zirconium are of most commercial importance. Chemical and physical standards for columbium and columbium alloy mill shapes are given in ASTM Specifications B391-B394, B652, and B654-B655.

Products for Trade and Industry

Columbium, in the form of ferrocolumbium, is used worldwide, principally as an additive to improve the strength and corrosion resistance of steel. Columbium-containing high-strength and corrosion resistant steel is used in applications such as high-strength linepipe, structural members, lightweight components in cars and trucks, and exhaust manifolds. Because of its refractory nature, appreciable amounts of columbium in the form of high-purity ferrocolumbium and nickel columbium are used in nickel-, cobalt-, and iron-base superalloys for applications such as jet engine components, rocket subassemblies, and heat-resisting and combustion equipment. Columbium-base alloys are also used in aerospace applications such as rocket nozzles. Columbium carbide is used in cemented carbides to modify the properties of the cobalt-bonded tungsten carbide-base material. It is usually used with carbides of metals such as tantalum and titanium. Columbium oxide is the intermediate product used in the manufacture of high-purity ferrocolumbium, nickel columbium, columbium metal, and columbium carbide.

Geology-Resources

Columbium is almost always found in nature as an oxide in association with other minerals, but not in elemental form nor as a sulfide. Columbium has an overall crustal abundance estimated as 20 parts per million and a strong geochemical coherence with tantalum. Pyrochlore and bariopyrochlore (also known as pandaite), its barium analog, have become the main sources of columbium. The minerals contain little tantalum, having a columbium oxide-to-tantalum oxide ratio of 200:1 or greater. Pyrochlore and bariopyrochlore are commonly found in the interior parts of alkalic rock complexes, frequently in association with minerals of such other elements as thorium, titanium, uranium, and those of the rare earths. Columbite, the columbium-rich member of the columbite-tantalite isomorphous series, is normally found in intrusive pegmatites and in biotite and alkalic granites. However, because most such deposits relatively high in columbium content are small and erratically distributed, most columbite has been obtained as a byproduct of mining for other commodities, mainly tin.

Reserve and reserve base data for columbium are shown in table 1 and are based on a judgmental appraisal of current information. Reserve base is defined as the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. The reserve base may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. Reserves are defined as that part of the reserve base that could be economically extracted or produced at the time of determination.

Technology

Exploration.—Columbium deposits of economic interest are most likely to be found in alkalic rock complexes and associated carbonatites. Aerial photography and geological mapping can

be used to reveal alkalic complexes, which frequently occur with circular geometry and concentric rock arrangement. Test pitting and panning can be used to explore placer deposits for columbium by virtue of the high specific gravity of columbium minerals. The columbium content of samples can be determined rapidly by means of truck-mounted spectrographic equipment and X-ray fluorescence spectroscopy.

Mining.—Pyrochlore has been mined mainly by mechanized open pit, underground stoping methods, or a combination of both. Currently, all mining for pyrochlore in Brazil is open pit, whereas in Canada, underground mining is being done via a large-diameter blasthole method. Ore, with host rock, is usually dislodged from a working face with explosives. Beneficiation of the ore, after it has been finely ground, is achieved primarily by various flotation procedures combined with magnetic separation to remove iron minerals. A chloridizing and leaching process can also be employed to lower barium, lead, phosphorus, and sulfur contents. Methods used to mine columbite have ranged from simple hand operations in small pegmatite mines to hydraulic monitors and dredges at placer deposits.

Beneficiation.—Pyrochlore concentrates are used solely in the manufacture of ferrocolumbium for steelmaking. Aluminothermy, the process being used for making steelmaking-grade ferrocolumbium from pyrochlore concentrates, is carried out in batches. As practiced by Cia. Brasileira de Metalurgia e Mineração (CBMM) in Brazil, a mixed charge of concentrate, iron oxide (as hematite), fine aluminum powder, and slagging agents is reacted to produce ferrocolumbium in a refractory-lined, cylindrical steel shell open at the top and resting upon a lined silica sand bed. Also, processes have been developed for production of columbium oxide through treatment of ferrocolumbium produced from pyrochlore concentrates. This technology is being used to produce commercial

quantities of columbium oxide suitable for the manufacture of high-purity ferrocolumbium, nickel columbium, and columbium metal.

In the extraction of columbium from other mineral concentrates and tin slags, modern technology makes use mainly of digestion with hydrofluoric acid followed by liquid-liquid extraction with methyl isobutyl ketone (MIBK). This procedure efficiently recovers both columbium and tantalum in the form of separate streams that then can be further processed individually into oxides and metal. Columbium oxide is precipitated from the columbium stream by ammonia and then purified and calcined.

Columbium oxide is aluminothermally reduced batchwise to produce high-purity ferrocolumbium, nickel columbium, and columbium metal. Aluminothermally produced columbium metal is commonly purified to remove aluminum and other contaminants by remelting it in an electron-beam furnace. Several remelts may be required before the desired level of purity is reached and a ductile ingot has been produced. The basic method for production of columbium carbide is reduction of columbium oxide by carbon at high temperature under vacuum or a protective atmosphere.

Recycling.—Columbium used in steelmaking and in superalloy manufacture is essentially a dissipative use, and little is reclaimed. However, when strict scrap segregation practices are followed, small quantities of columbium-bearing superalloy scrap are recycled. Aside from sales to alloy melters, columbium metal scrap has not been recycled to any extent other than in-house as home scrap by processors.

Byproducts and Coproducts

In Africa, Australia, Brazil, Malaysia, and Thailand, columbium, as well as tantalum, is produced as a byproduct and/or coproduct of tin mining. Columbium and tantalum can also be recovered economically from some tin slags, which constitute an important raw

material source for high-purity columbium and tantalum. Other elements frequently associated with columbium deposits include rare earths, thorium, titanium, and uranium; some of these have been recovered along with columbium in the past and may be coextracted in the future.

Substitutes

For established applications of both columbium-bearing steels and superalloys, substitution of some alternative steel or alloy requiring less columbium ordinarily lowers performance and/or cost effectiveness. In some high-strength low-alloy (HSLA) steels, use of columbium as a microalloying element competes with use of such elements as molybdenum, titanium, and vanadium. In other HSLA steels, it may be desirable to use one or more of these elements along with columbium in complementary fashion. Tantalum is a costly potential substitute for columbium in superalloys. Titanium can be used instead of columbium in stainless steel to improve corrosion resistance.

Economic Factors

Prices.—Time-price relationships for columbium contained in concentrates in terms of actual prices and in constant 1987 dollars are shown in table 2 and figure 1. Actual prices reported are based on historical price quotations or best available information from producers.

By the end of World War II, new columbium-bearing superalloys were being used in jet airplane engines. Subsequently, the involvement of the United States in the Korean conflict, and the rapid expansion of jet-engine production during this period resulted in columbium concentrate shortages and increased prices. Additionally, the demand for ore to produce ferrocolumbium had outstripped the available supply of columbium-bearing materials. However, a significant activity during this period was the U.S. Government-guaranteed worldwide 100% bonus

purchase program under title III of the Defense Production Act. The program was initiated to encourage increased production of columbium-tantalum ore and concentrates of both domestic and foreign origin.

In May 1952, the Defense Materials Procurement Agency (DMPA) announced its schedule for the purchase of columbium concentrates for the National Stockpile at an average price of \$3.40 per pound of combined columbium-tantalum oxides. The program was such a success in the expansion of supply that in only 3 years the stockpile had acquired 15 million pounds of columbium and tantalum oxides contained in columbium concentrates.

Having achieved its basic objectives, the U.S. Government stopped buying foreign material under the program in May 1955. Small-lot purchases of domestically produced material continued until 1958. The DMPA purchase price had largely governed the market quotations for columbium concentrates, and termination of the program was followed by lower prices and reduced production worldwide.

With the trend of increasing columbium demand, concentrate prices began to escalate in the mid-1970's with the peak year occurring in 1977. The price increase was attributed to inflation, higher labor costs, and resulting higher raw material costs.

In 1980, an important change in the nature of columbium supply occurred with the commercialization both in Brazil and the United States of plants for producing columbium oxide from pyrochlore-based materials. This event resulted in the lowering of prices for columbium oxide and high-purity columbium products. Columbium prices were lowered in much of the 1980's, owing to the large quantities of pyrochlore produced in Brazil and Canada, and the products produced from this feed material.

Depletion Provisions.—U.S. columbium-producing companies are granted a depletion allowance of 22% for domestic

production of columbium minerals and 14% on foreign production.

BACKGROUND—TANTALUM

Tantalum is a refractory metal that is ductile, easily fabricated, has a high melting point (2,996° C), is highly resistant to corrosion by acids, and is a good conductor of heat and electricity. It combines readily with other refractory metals such as hafnium and tungsten to form alloys having high-temperature strength and stability. Tantalum forms highly stable anodic films and exhibits a rectifying, or electronic valve, action in an electrolyte. Tantalum is twice as dense as steel with a specific gravity of 16.6.

Definitions, Grades, and Specifications

Metallic forms of tantalum are produced chiefly in unalloyed form or alloyed with up to about 10% tungsten. Unalloyed metal and alloys with tungsten are available as ingot, plate, sheet, strip, bar, rod, wire, and tubing in accordance with ASTM Specifications B364, B365, and B521. Allowable impurity levels do not exceed 0.3% in most cases; the main impurities are columbium and oxygen, plus tungsten in the case of unalloyed tantalum. Purity of tantalum metal powder is usually about 99.9%. Depending on powder usage, impurities that must be controlled consist mainly of calcium, carbon, columbium, iron, nickel, nitrogen, oxygen, silicon, and sodium. Commercial tantalum carbide usually contains about 93% tantalum and about 6.3% carbon.

Products for Trade and Industry

The major end use for tantalum, as tantalum metal powder, is in the production of electronic components, mainly tantalum capacitors. Applications for tantalum capacitors include computers, communication systems, and instruments and controls for aircraft, missiles, ships, and weapon systems. The tantalum capacitor exhibits reliable performance and combines compactness

and high efficiency with good shelflife. Because of its high melting point, good strength at elevated temperatures, and good corrosion resistance, tantalum is combined with cobalt, iron, and nickel to produce superalloys that are employed in aerospace structures and jet engine components. Tantalum carbide, used mostly in mixtures with carbides of such metals as columbium, titanium, and tungsten, is used in cemented-carbide cutting tools, wear-resistant parts, farm tools, and turning and boring tools. Because of its excellent corrosion resistant properties, tantalum mill and fabricated products are used in the chemical industry in applications such as heat exchangers, evaporators, condensers, pumps, and liners for reactors and tanks.

Geology-Resources

The principal source of tantalum is an isomorphous series of minerals containing columbium, iron, manganese, and tantalum oxides. Tantalum and columbium have strong geochemical affinity and are found together in most rocks and minerals in which they occur. Tantalite-columbite occurs mainly as accessory minerals disseminated in granitic rocks or in pegmatites associated with granites. The microlite-pyrochlore mineral series is also a source of tantalum. These minerals consist essentially of complex oxides of calcium, columbium, sodium, and tantalum in combination with hydroxyl ions and fluorides. Microlite occurs mainly in the albitized zones of granite pegmatites, often associated with tantalite or columbite. Struverite is a low-grade source of tantalum recoverable from tin-mining wastes in Southeast Asia. Struverite is a variation of the titanium mineral rutile. Tantalum is also obtained through byproduct recovery from tantalum-bearing tin slags, principally from smelters in Brazil and Southeast Asia.

Reserve and reserve base data for tantalum are shown in table 3 and are based on a judgmental appraisal of current information. Reserve base is defined as the in-place demonstrated

(measured plus indicated) resource from which reserves are estimated. The reserve base may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. Reserves are defined as that part of the reserve base that could be economically extracted or produced at the time of determination.

Technology

Exploration.—Exploration for tantalum is generally pursued on the basis of its known frequent association with tin and certain other elements in pegmatite environments, some features of which can be distinguished by aerial photography. Application of X-ray fluorescence analysis techniques has been helpful in measuring tantalum at the low concentrations at which it occurs. The high specific gravity of tantalum minerals makes it possible to reveal their presence in placer deposits by test pitting and panning.

Mining.—Most tantalum-related mining developments in the past generally were small, relatively high-cost intermittent operations that depended on the recovery of byproduct or coproduct minerals for economic viability. Future mine development will shift more to primary tantalum sources, notably operations in Australia.

Both alluvial and residual tantalum and tantalum-containing tin deposits are normally mined by hand, by hydraulic monitors, by dredges, or by mechanized open pit mining. The mining of pegmatite deposits, which may be either open pit or underground, is carried out by blasting, transporting, and crushing the rock to free the tantalum and associated coproduct minerals. The materials are then concentrated by wet gravity methods (sluices, jigs, spirals, and tables) and finally separated from associated minerals by gravity and electrostatic and electromagnetic processes.

Tantalum is recovered from slags produced at tin smelters throughout the world. Tantalum content varies in tin slag depending on ore and smelting practice.

Beneficiation.—Tantalum mineral concentrates and tin slags are the predominant feed materials for preparation of tantalum metal and compounds. Both raw materials usually contain recoverable amounts of columbium as well. Depending on circumstances, tin slags may be used directly for extraction of tantalum or they may be first upgraded. Upgrading is typically performed by means of an electric furnace process that yields a synthetic concentrate.

In the extraction of tantalum from these source materials, technology makes use mainly of digestion with hydrofluoric acid followed by liquid-liquid extraction with MIBK. This procedure efficiently recovers both tantalum and columbium in the form of separate streams that then can be further processed individually into salts, oxides, and metal. The two streams are produced by a series of countercurrent extractions that also remove impurities. The tantalum product stream is a fluotantallic acid solution from which either potassium fluotantalate (K-salt), by addition of potassium chloride or fluoride, or tantalum pentoxide, by addition of ammonia, can be precipitated. Reducing K-salt by sodium is the standard commercial method for making tantalum metal. The product of sodium reduction is a powder that is consolidated by a pressing, vacuum sintering, and melting sequence.

Tantalum carbide can be manufactured by several methods, the most common being solid-state reaction between tantalum oxide and carbon. Tantalum carbide can also be made by reacting metallic tantalum directly with carbon.

Recycling.—Recycling of tantalum largely takes place within the processing and product producing industry and is mostly runaround or home scrap that is consumed internally. In addition,

quantities of tantalum are recycled indirectly in the form of used tantalum-bearing cutting tools and high-temperature alloy melting scrap.

Byproducts and Coproducts

Economic exploitation of tantalum minerals often is dependent on the price of associated recoverable byproduct or coproduct minerals, principally tin and columbium. Tantalite-columbite minerals occur in deposits associated with beryllium, lithium, rare-earth, tin, titanium, tungsten, uranium, and zirconium minerals. Minerals associated with tantalum in pegmatite deposits include beryl, feldspar, lepidolite, mica, pollucite, and spodumene. Tantalum and columbium can also be recovered economically from some tin slags, which constitute an important raw material source for tantalum and high-purity columbium. Tantalum is usually extracted in conjunction with columbium in much the same type of equipment.

Substitutes

Substitution for tantalum is usually made at a performance or economic penalty for most uses. Also, substitution requires both investment and experimentation and does not necessarily occur quickly. Aluminum and ceramics compete strongly with tantalum for use in electronic capacitors. In cemented carbides, columbium carbide and columbium-hafnium carbide can take the place of tantalum carbide in some cutting tools. Replacements for tantalum in corrosion-resistant equipment are columbium, glass, platinum, titanium, and zirconium. Columbium, hafnium, molybdenum, tungsten, and some platinum-group metals can be substituted for tantalum in high-temperature applications.

Economic Factors

Prices.—Time-price relationships for tantalum contained in concentrates in terms of actual prices and in constant

1987 dollars are shown in table 4 and figure 2. Actual prices reported are based on historical price quotations or best available information from producers. The prices show large swings between the high and low in response to market conditions.

The Korean conflict in 1950 increased demand for tantalum in military requirements. Thus, consumption rose sharply with resulting ore shortages. During this period, the U.S. Government-guaranteed worldwide 100% bonus purchase program was initiated to increase production of columbium-tantalum ore and concentrates of both domestic and foreign origin. In May 1952, a schedule was announced for the purchase of 15 million pounds of the combined columbium-tantalum oxides at prices about double prevailing world prices. The program had the effect of increasing tantalum ore prices to a high of \$8 per pound of oxide.

Having achieved its basic procurement objectives, the purchase of foreign material was stopped in May 1955. Small-lot purchases of domestically produced material continued until December 1958. When Government purchase of domestic ore stopped, the immediate effect was a confused market in which production and prices of ore began to drift downward. By 1959, prices for tantalum ore had dropped to about \$4 per pound of oxide.

By 1960, tantalum demand for use in capacitors, high-temperature alloys, corrosion-resistant chemical applications, machine cutting tools, and aerospace applications had increased substantially. During the 1960's, the variations in supply and demand resulted in a repetition of 2 or 3 years of oversupply with lower prices followed by 2 or 3 years of high demand with higher prices. Price peaks in 1961 and 1966 were occasioned by a sudden increase in demand for tantalum, which outstripped the supply, driving prices up. This cyclical trend continued into the 1970's.

The 1970's can be characterized as a decade of increasing tantalum demand, ore shortages, escalating prices, and substitution. A 7-year trend of declining

price, 1967-73, was followed by a trend of rapid price increase that was sustained through midyear 1980. The record price levels during this period were attributed in part to a state of panic buying influenced by anticipated greater tantalum demand, amidst concerns at the time of a shrinking world tantalum supply. The high prices brought about substitution for tantalum and more widespread search for and development of new tantalum sources. However, prices began declining by yearend 1980 and by midyear 1986 were the lowest since first quarter 1977, hastened by a weak tantalum demand and an increase in tantalum material stockpiles. Subsequently, prices rebounded through yearend 1988 and were at the highest level since the third quarter of 1981, responding to increased demand for feed materials along with the drawdown of stockpiles. The price of tantalum continued its cyclic pattern, and the 1991 average price quote was about \$30 per pound of oxide.

Depletion Provisions.—U.S. tantalum-producing companies are granted a depletion allowance of 22% for domestic production of tantalum minerals and 14% on foreign production.

ANNUAL REVIEW— COLUMBIUM AND TANTALUM

Legislation and Government Programs

At yearend, Government stocks of columbium and tantalum in the NDS were the same as those in 1990 (table 7). The overall goal of the columbium group, on a recoverable basis, was 5.68 million kilograms (12.52 million pounds). The overall goal for the tantalum group, on a recoverable basis, was 3.25 million kilograms (7.16 million pounds). Under the offset concept for the NDS, less than 25% of the goal for columbium concentrates and 37% of the goal for tantalum minerals were met.

In July, the Department of Defense issued a report to Congress recommend-

ing revisions to stockpile material goals, including those for the columbium and tantalum groups. The goal for the columbium group would increase from 6.02 million kilograms (13.27 million pounds) to 7.99 million kilograms (17.6 million pounds). The goal for tantalum minerals would decrease from 3.81 million kilograms (8.4 million pounds) to 2.88 million kilograms (6.34 million pounds). The proposed goals, based on 1989 supply and demand data, were said by the Department to continue to meet a 3-year global conventional war. At yearend, Congress had not yet approved the proposed goal revisions.

In its "Strategic and Critical Materials Report To The Congress, April 1991-September 1991," the Department of Defense reported that 59,251 kilograms (130,626 pounds) of tantalum material had been accepted and received into the stockpile. However, status (inventory) of the material had not been determined. The material was part of the 90,718 kilograms (200,000 pounds) of tantalum oxide contained in tantalum natural minerals and concentrates contracted for in 1990 from Sogem-Afrimet, New York, NY, and O'Dell Construction Co., Prattville, AL.

In September, the DLA awarded a contract to purchase 90,718 kilograms (200,000 pounds) of the product "tantalum oxide" for the NDS. The material will conform to the requirements for Grade 2 tantalum oxide, as modified, stated in National Stockpile Purchase Specification P-113a, Tantalum Source Materials, dated August 3, 1981. The award was made to O'Dell Construction, one of eight bidding firms.

The award was for eight 11,340-kilogram (25,000-pound) allotments at a purchase price of \$55.00 per pound of tantalum oxide for each of the eight lots. Bid prices for the eight allotments, under varying bid conditions, ranged from \$47.88 to \$145.00 per pound of tantalum oxide. The material shall be delivered between January 1, 1992, and March 31, 1994, to be placed equally in NDS storage depots at New Haven, ID, and Somerville, NJ. Payment for the tantalum oxide, including transportation,

will be made with excess material available for disposal under the Stockpile Disposal Program.

In its revised fiscal year 1992 Annual Materials Plan for the NDS, the Department of Defense provided for the acquisition of 113,400 kilograms (250,000 pounds) of columbium for the columbium group and 28,576 kilograms (63,000 pounds) of tantalum metal. Additionally, some existing columbium and tantalum stockpile materials would be upgraded: 204 metric tons (225 short tons) of columbium-tantalum concentrates to columbium and tantalum metal, 18,144 kilograms (40,000 pounds) of tantalum powder to vacuum-grade metal, and 20,412 kilograms (45,000 pounds) of columbium powder to vacuum-grade metal.

In August, the Memphis region of the Defense Reutilization and Marketing Service reportedly sold two lots of tantalum capacitor scrap at a sale of nonferrous recyclables at Warner Robbins Air Force Base, GA. EDS Enterprises Co., Upland, GA, was the high bidder for both lots. One 268-kilogram (590-pound) lot of tantalum capacitor scrap, silver coated, attracted a high bid of \$13.88 per pound. The other 488-kilogram (1,075-pound) lot of tantalum capacitor scrap attracted a high bid of \$4.48 per pound.¹

Strategic Considerations

The high degree of import reliance for columbium and tantalum continues to be the principal strategic problem faced by the United States. Summaries of important columbium and tantalum statistics are shown in tables 5 and 6, respectively. In the case of both columbium and tantalum, there has been no significant mining since the 1950's. Domestic columbium and tantalum resources are of low grade, some mineralogically complex, and most are not currently commercially recoverable. To ensure a supply of columbium and tantalum during an emergency, goals for both materials have been established for the NDS. However, inventories for both materials are substantially under set

goals. Consequently, a degree of vulnerability still remains.

The NDS goals and inventory for both columbium and tantalum are mostly for source materials (feedstocks). However, the United States has become more reliant on the processing capability of foreign sources and the availability of intermediate products from those sources. At the start of the 1980's, there were four major processors of columbium- and tantalum-bearing source materials. One of the operations was shut down in 1985, and another shut down its processing operation at yearend 1989. Of the remaining two companies, one is dedicated solely to the processing of columbium materials, whereas the other company processes both columbium and tantalum materials. Thus, there is concern whether the United States would have on hand in an emergency adequate processing capacity for conversion of the stockpile materials to an upgraded form and quality required by the critical end uses.

Production

In 1991, there were two processors of columbium- and tantalum-bearing source materials that were integrated from raw material processing to columbium and tantalum end products: Cabot Corp. for columbium and tantalum processing and Shieldalloy Metallurgical Corp., dedicated solely to columbium processing. NRC Inc., a major supplier, and Thai Tantalum Inc. produced tantalum products. Reading Alloys Inc. and Teledyne Wah Chang Albany were major producers of high-purity columbium products. Kennametal Inc. was the major producer of columbium and tantalum carbides. Major domestic columbium and tantalum processing and producing companies are shown in table 8.

Early in the year, Shieldalloy, a Metallurg Inc. subsidiary, announced that all management functions previously located at the Metallurg headquarters in New York had been transferred to its Newfield, NJ, plant effective January 1. The consolidation of management and

operation functions was said to be for the overall improvement in communications and efficiency at the company. Additionally, Metallurg reported that a new division, Metallurg International Resources, had been created early in the year to conduct all export and trading activities previously conducted by the company.

In April, the Unocal Corp. announced that its Molycorp Inc. subsidiary and parts of its chemical businesses were still up for sale. Molycorp, based in Los Angeles, CA, holds a 45% interest in the world's largest producer and supplier of columbium products, CBMM of Brazil.

Consumption and Uses

Overall reported consumption of columbium as ferrocolumbium and nickel columbium was down by 7% compared with that of 1990 (see table 10). Consumption of columbium by the steelmaking industry was down by 9%, in line with an 11% decrease in raw steel production. There was a small increase in the percentage of columbium usage per ton of steel produced. Columbium consumption in carbon steel decreased by 35%, while columbium consumption in HSLA steel advanced by 20%. Demand for columbium in superalloys was up slightly. That portion used in the form of nickel columbium increased to more than 280,000 kilograms, reflecting a significant shift from ferrocolumbium. U.S. columbium consumption in 1990, by end use, is shown in figure 3.

Overall consumption of tantalum was down from that of 1990. Factory sales of tantalum capacitors were up by 9%, as reported by the Electronic Industries Association. However, the amount of capacitor-grade powder consumed was on the decline owing to the continued use of higher capacitance tantalum powders. U.S. tantalum consumption in 1990, by end use, is shown in figure 4.

Markets and Prices

A published price for pyrochlore concentrates was not available. The published price for pyrochlore produced

in Canada was suspended in early 1989. However, industry sources indicated that Canadian pyrochlore was about \$2.75 per pound of contained Cb_2O_3 , f.o.b. Canada. A price for Brazilian pyrochlore has not been available since 1981 when exports were stopped. The Metals Week published price for regular-grade ferrocolumbium was unchanged throughout the year at \$6.58 per pound of contained columbium, f.o.b. shipping port.

The Metals Week published spot price for columbite ore, quoted since July 1989 at a range of \$3.00 to \$3.50 per pound of contained Cb_2O_3 and Ta_2O_5 , c.i.f. U.S. ports, was suspended in February. The Metal Bulletin published price for columbite ore, on the basis of a minimum 65% contained Cb_2O_3 and Ta_2O_5 , remained unchanged at a range of \$2.60 to \$3.05 per pound. For the year, the Metals Week published price for high-purity ferrocolumbium containing 62% to 68% columbium was quoted at \$18.50 per pound of contained columbium, f.o.b. shipping point, and the published price for nickel columbium was quoted at \$20.50 per pound of contained columbium. Metals Week's published price for columbium oxide was \$8.17 per pound of oxide, and its published price for columbium metal was at a range of \$30 to \$50.

The Metals Week published spot price for tantalite ore fell from a range of \$31 to \$35 per pound of contained Cb_2O_3 and Ta_2O_5 , c.i.f. U.S. ports, to a range of \$27.50 to \$29.00 in early October, where it remained through December. The Metal Bulletin published price for tantalite remained unchanged at a range of \$34 to \$37 per pound of contained Ta_2O_5 . The Metal Bulletin published price for tantalite produced by Greenbushes Ltd. of Australia, quoted since February 1989 at \$50 per pound on the basis of 40% contained Ta_2O_5 , fell to \$40 per pound in mid-April, where it remained through December. A published price for tantalite from the Canadian producer, Tantalum Mining Corp. of Canada Ltd. (TANCO), was not available. Industry sources indicated that tantalum mill products sold at an average

of \$170 per pound, depending on specification, and that tantalum capacitor-grade powder sold at an average of \$145 per pound.

Foreign Trade

Net trade for columbium and tantalum continued at a deficit, but closed to the lowest level since 1986. Overall trade value for exports rose by 11%, with total volume up by 17% owing to significant increases in the volume of ferrocolumbium and wrought tantalum exports. For imports, trade value was down by 8%. Data for exports and imports are summarized in table 11.

Imports for consumption of columbium mineral concentrates increased by 12% from those of 1990 (see table 12). Canada was the leading supplier, providing about 90% of both total quantity and total value. Imports at an average grade of approximately 58% Cb_2O_3 and 3% Ta_2O_5 were estimated to contain 1.01 million kilograms of columbium and 60,000 kilograms of tantalum.

Imports for consumption of tantalum mineral concentrates continued to decline, with the average unit value for overall imports decreasing by 16% (see table 13). Imports from Germany and Japan, both nonproducing countries, together accounted for about 40% of total quantity and about 36% of total value. Imports at an average grade of approximately 37% Ta_2O_5 and 23% Cb_2O_3 were estimated to contain 280,000 kilograms of tantalum and 150,000 kilograms of columbium.

Imports for consumption of synthetic tantalum-columbium concentrates totaled 63,000 kilograms valued at \$741,000, compared with 51,000 kilograms valued at \$1.5 million in 1990. These figures are not included in the salient statistics data.

Brazil continued as the major source for U.S. columbium imports, and Germany continued as the major source for U.S. tantalum imports (see figures 5 and 6). The schedule of tariffs that applied during 1991 to U.S. imports of selected columbium and tantalum materials is given in table 14.

World Review

Industry Structure.—Principal world columbium and tantalum raw material and product producers are shown in tables 15 and 16, respectively. Brazil and Canada remained as the major producers of columbium raw materials feedstock, while tantalum raw materials continued to be produced mainly in Australia, Brazil, Canada, and in Thailand in the form of high-grade tantalum-bearing tin slags. Synthetic concentrates, produced from low-grade tin slags from Germany, were an additional source of columbium and tantalum raw material supply. Annual world production of columbium and tantalum mineral concentrates, by country, is given in table 18. World tantalum supply in 1981-91 is shown in figure 7.

Capacity.—The data in table 17 are rated capacity for mines and mills as of December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgement of the author, can be brought into production within a short period of time with minimum capital expenditure. Mine capacity for columbium and tantalum is based on published reports, maximum production statistics, and estimates where capacity information is either incomplete or unavailable.

Australia.—For its fiscal year ending June 30, 1991, Gwalia Consolidated Ltd. reported that tantalite output at its Greenbushes Mine, southwest Western Australia, had increased gradually during the year from annual rates of 122,470 kilograms in the first quarter to 181,437 kilograms in the fourth quarter. Ore treated at Greenbushes almost doubled to 2.985 million tons, with tantalum oxide

production in tantalum concentrates increasing to about 146,000 kilograms. Tantalum oxide contained in tantalum glass (slag) production fell to 37,430 kilograms.²

A feasibility study to evaluate and consider the various alternatives and requirements necessary to operate and/or upgrade existing operations at Greenbushes to maximize production at the lowest possible cost was completed. Results of the study reportedly indicated sufficient positive returns to enable Gwalia to proceed with recapitalization of the mine. The study concluded that "tin/tantalum and spodumene ores should continue to be produced from open pits, with the transition from weathered to fresh pegmatite ores for the tin/tantalum sector." Construction of a new tantalum processing facility for treating the harder ores would be required. Thus, a decision was made to proceed with development of the tantalum hard-rock operations and to construct new tantalum processing facilities. Plans were made for commencing plant construction by yearend, with commissioning of the new facilities scheduled for about October 1992.

Additionally, Gwalia announced that the company had entered into contracts with two of the world's largest tantalum processors, Cabot Corp. and Hermann C. Starck, for the long-term supply of tantalite concentrates. The initial contracts are for a period of 5 years, with concentrates to be supplied at fixed volumes and prices to be set on an annual basis. Quantities to be delivered under the secured contracts are for a minimum of 0.907 million kilograms of contained Ta_2O_5 and a maximum of 1.089 million kilograms of Ta_2O_5 over the next 5 years.

As reported by Pancontinental Mining Ltd. for its fiscal year ending June 30, 1991, tantalum production at the Wodgina Mine was about 127,000 kilograms of Ta_2O_5 contained in concentrate. A total of 88,172 tons of ore grading 0.1892% Ta_2O_5 was processed in the treatment plant yielding 286.2 tons of concentrate grading 44.4% Ta_2O_5 , with a metallurgical recovery of 76%. The mine, 120 kilometers south of Port

Hedland in the Pilbara region of Western Australia, is a 50-50 joint venture between Pancontinental and Goldrim Mining Australia Ltd. Pan West Tantalum Pty. Ltd., a wholly owned subsidiary of Pancontinental, is the operator of the joint venture. A small metallurgical laboratory was constructed and commissioned on-site to monitor plant performance and to test new techniques and/or equipment that have potential for improving recoveries.³ The 1991 reporting period was the first full year of operation at Wodgina, which was officially opened by the Western Australian Minister for Resources in February 1990.

Brazil.—CBMM was reported to have installed a new semicontinuous autothermic reduction process to produce standard-grade (steelmaking-grade) ferrocolumbium at its facility in Araxa. CBMM had relied on the conventional batch thermite process, developed during the 1960's, to produce the ferrocolumbium. The new process, designed and constructed by CBMM, was said to have led to the elimination of atmospheric pollution and minimized the impact of cost increases. As reported previously, the new plant will have an annual ferrocolumbium capacity of about 25,000 tons.

Associação Brasileira dos Produtores de Ferroligas (ABRAFE), the Brazilian ferroalloy producers association, reported 1991 production of ferrocolumbium as 18,959 tons, up from the 16,643 tons produced in 1990. ABRAFE reported exports of ferrocolumbium totaled 15,163 tons compared with 13,360 tons exported in 1990.

Canada.—As reported by Teck Corp., production of Cb_2O_5 at the Niobec Mine at St. Honoré, Quebec, decreased slightly to about 3.37 million kilograms. Niobec is a 50-50 joint venture between Teck, operator, and Cambior Inc., product marketing. Ore milled increased to 805,000 tons, as the mill operated on the average of 2,242 tons of ore per day. Average recovery was down to 60.2%

with Cb_2O_5 grade of concentrate at 70%. Due to the frequent changes in the character of the ore, which can complicate the milling process, an on-stream analyzer costing \$650,000 was installed to improve ore process control. Exploration drilling during 1991 established new ore reserves that essentially replaced ore processed during the year. Thus, yearend ore reserves remained at 10.1 million tons averaging 0.65% Cb_2O_5 .⁴

Japan.—Production of ferrocolumbium was 710 tons, down significantly from the 984 tons produced in 1990. With the exception of Japan Metals & Chemicals Co. Ltd., it was reported that all other ferrocolumbium producers had ceased production by July. However, The TEX Report reported that Japan's demand for ferrocolumbium for steelmaking was 4,398 tons, an alltime high. Columbium ore imported for ferrocolumbium production increased by 15% to 1,347 tons, with Canada continuing to provide more than 80% of the total. Ferrocolumbium imports rose to 4,526 tons from the 3,516 tons reported in 1990. The bulk of ferrocolumbium imports continued to come from Brazil. Columbium consumption in Japan reportedly continues to increase owing to demand from its automakers.

Roskill's Letter from Japan reported that Japan's demand for tantalum materials rose to 274 tons from the 264 tons reported for 1990.

Thailand.—To compensate for the decrease in Thailand's tin concentrate output, the Thailand Smelting and Refining Co. Ltd. (Thaisarco) tin smelter was reported to have purchased concentrates from the Laos state-owned Société de Exploitation des Mines D'Etaine. Thaisarco, with an annual tin capacity of 38,000 tons, sought to find alternate sources of supply in light of Thailand's declining tin concentrate production. However, Thai tin concentrates are high in tantalum content from which the Thaisarco smelter produces a

tantalum-bearing slag containing up to 17% Ta_2O_5 . Increasing the throughput of imported concentrates could result in reduced tantalum content of the slags. Thaisarco-produced tantalum-bearing tin slags have been a major source of world tantalum supply for years. The smelter has an annual capacity to produce from Thai concentrates about 318,000 kilograms of tantalum contained in slags.

Thai Tantalum Co. Ltd. was reported to have revised the scheduled startup of its tantalum processing plant, to occur by yearend 1992. The plant is being constructed at the Map Ta Phut Industrial Estate in Rayong Province east of Bangkok. When operational, the new facility reportedly will have an annual capacity of 300 tons of intermediate tantalum products.

OUTLOOK

Columbium

Columbium is used principally as an additive in steelmaking, which continues to account for about 80% of the reported consumption in the United States. No significant change to this trend is expected in the near term for there are few other growth markets and/or uses for columbium. Thus, future columbium demand growth will continue to be directly related to the worldwide performance of the steel industry. U.S. apparent consumption of columbium has been in the range of 3,200 to 3,600 tons of contained columbium for the period 1987-91, and any major future variations from this trend will depend on future activities of the domestic steel industry. The outlook for steel is discussed in the annual report for "Iron and Steel." The outlook for columbium will also be dependent to a lesser degree on the performance of the aerospace industry. Domestic reported consumption of columbium in the production of superalloys continues to be no more than 20%. Future growth for this end use will be affected mainly by the demand for columbium-containing superalloys from the aircraft industry. However, industry sources indicate that continued reduction

in military spending is expected to lead to reduced aerospace shipments throughout the decade. The major components of U.S. supply-demand relationships for columbium in 1981-91 are given in table 19.

Tantalum

For the past decade, more than 60% of the tantalum consumed in the United States was used to produce electronic components, mainly tantalum capacitors, with major markets in recent years being computer and communication systems. However, overall tantalum demand growth in this sector has been slowed owing to the industry's continued emphasis on higher capacitance powders and the miniaturization of electronic components resulting in less tantalum used per unit. Also, tantalum demand in the cemented carbide sector continues to be affected by the growing use of mixed carbides, coated cutting tools, improved tool life, and the down-sizing of components. Additionally, the price for tantalum has had a cyclical and somewhat volatile history that has adversely impacted demand. However, major tantalum processors have entered into long-term contracts for the supply of tantalum concentrates. Under terms of the contracts, material would be supplied at fixed volumes and prices on an annual basis for a period of 5 years. With the award of these contracts, future stability in the supply and price of tantalum is anticipated. The major components of U.S. supply-demand relationships for tantalum in 1981-91 are given in table 20.

¹American Metal Market. Tantalum Highlight of Defense Auction. V. 99, No. 161, Aug. 22, 1991, p. 6.

²Gwalia Consolidated Ltd. 1991 Annual Report. 63 pp.

³Pancontinental Mining Ltd. 1991 Annual Report. 73 pp.

⁴Teck Corp. 1991 Annual Report. 57 pp.

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TABLE 1
WORLD COLUMBIUM RESERVES AND RESERVE BASE, 1991

(Thousand kilograms columbium content)

Country	Reserves	Reserve base ¹
Brazil	3,311,000	3,629,000
Canada	136,000	408,000
Nigeria	64,000	91,000
United States	—	(²)
Zaire	32,000	91,000
Other market economy countries	6,000	9,000
World total	3,549,000	4,228,000

¹The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).

²Negligible.

TABLE 2
TIME-PRICE RELATIONSHIPS
FOR COLUMBIUM

Year	Average annual price, dollars per pound of contained columbium in concentrates	
	Actual price	Based on constant 1987 dollars
1954	4.86	21.70
1955	1.93	8.33
1956	1.79	7.48
1957	1.68	6.78
1958	1.54	6.09
1959	1.54	5.95
1960	1.73	6.57
1961	1.43	5.38
1962	1.36	5.01
1963	1.36	4.93
1964	1.36	4.85
1965	1.34	4.65
1966	1.43	4.80
1967	1.42	4.64
1968	1.42	4.42
1969	1.42	4.19
1970	1.65	4.61
1971	1.65	4.36
1972	1.87	4.72
1973	1.97	4.67
1974	2.23	4.85
1975	2.23	4.41
1976	2.73	5.08
1977	5.53	9.65
1978	3.69	6.00
1979	3.79	5.66
1980	4.55	6.23
1981	4.87	6.08
1982	4.83	5.67
1983	4.73	5.34
1984	4.71	5.13
1985	4.63	4.90
1986	3.78	3.90
1987	3.71	3.71
1988	3.71	3.59
1989*	3.93	3.65
1990*	3.93	3.51
1991*	3.93	3.36

*Estimated.

TABLE 3
WORLD TANTALUM RESERVES AND RESERVE BASE, 1991

(Thousand kilograms tantalum content)

Country	Reserves	Reserve base ¹
Australia	4,500	9,100
Brazil	900	1,400
Canada	1,800	2,300
Malaysia	900	1,800
Nigeria	3,200	4,500
Thailand	7,300	9,100
United States	—	(2)
Zaire	1,800	4,500
Other market economy countries	1,400	1,800
World total	21,800	34,500

¹The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).

²Negligible.

TABLE 4
TIME-PRICE RELATIONSHIPS FOR TANTALUM

Year	Average annual price, dollars per pound of contained tantalum in concentrates ¹	
	Actual price	Based on constant 1987 dollars
1954	9.77	43.62
1955	9.91	42.77
1956	7.96	33.25
1957	7.63	30.78
1958	5.18	20.47
1959	4.92	19.00
1960	7.28	27.66
1961	11.11	41.80
1962	7.29	26.83
1963	7.93	28.73
1964	7.31	26.09
1965	10.26	35.64
1966	14.72	49.38
1967	12.24	40.03
1968	9.13	28.43
1969	9.15	26.99
1970	9.15	25.57
1971	8.26	21.84
1972	8.09	20.42
1973	8.00	18.98
1974	14.13	30.72
1975	18.32	36.27
1976	20.31	37.79
1977	25.64	44.72
1978	34.19	55.59
1979	80.00	119.49
1980	126.37	173.11
1981	99.51	124.28
1982	49.95	58.64
1983	30.60	34.58
1984	37.44	40.81
1985	33.68	35.66
1986	23.74	24.49
1987	27.08	27.08
1988	47.37	45.85
1989	44.93	41.76
1990	38.06	33.98
1991	36.70	31.37

¹60% basis, combined tantalum and columbium pentoxides.

TABLE 5
SALIENT COLUMBIUM STATISTICS

(Thousand kilograms of columbium content unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Mine production of columbium-tantalum concentrates	—	—	(¹)	(¹)	(¹)
Releases from Government excesses	—	—	—	—	—
Consumption of raw materials ^a	W	NA	NA	NA	NA
Production of ferrocolumbium	W	NA	NA	NA	NA
Consumption of primary products:					
Ferrocolumbium and nickel columbium ^b	2,349	2,665	2,439	2,586	2,409
Exports: Columbium metal, compounds, alloys (gross weight) ^b	59	54	NA	NA	NA
Imports for consumption:					
Mineral concentrates ^a	912	794	1,216	1,125	1,160
Columbium metal and columbium-bearing alloys ^a	19	15	12	2	1
Ferrocolumbium ^a	1,822	1,922	2,411	1,897	2,133
Tin slags ^{a 2}	W	NA	NA	NA	NA
World: Production of columbium-tantalum concentrates^a	9,358	16,876	14,056	13,298	13,847

^aEstimated. ^bRevised. NA Not available. W Withheld to avoid disclosing company proprietary data.

¹A small unreported quantity was produced.

²Receipts reported by consumers; includes synthetic concentrates and other miscellaneous materials, after deduction of reshipments.

TABLE 6
SALIENT TANTALUM STATISTICS

(Thousand kilograms of tantalum content unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Mine production of columbium-tantalum concentrates	—	—	(¹)	(¹)	(¹)
Releases from Government excesses	—	—	—	—	—
Consumption of raw materials ⁵	W	NA	NA	NA	NA
Exports:					
Tantalum ores and concentrates (gross weight) ²	47	97	4	1	11
Tantalum metal, compounds, alloys (gross weight)	187	221	162	¹ 161	219
Tantalum and tantalum alloy powder (gross weight)	88	126	96	82	66
Imports for consumption:					
Mineral concentrates ⁶	100	181	499	299	340
Tantalum metal and tantalum-bearing alloys ³	27	58	37	21	19
Tin slags ⁴	W	NA	NA	NA	NA
World: Production of columbium-tantalum concentrates⁵	275	291	378	¹366	423

⁵Estimated. ⁶Revised. NA Not available. W Withheld to avoid disclosing company proprietary data.

¹A small unreported quantity was produced.

²Includes reexports.

³Exclusive of waste and scrap.

⁴Receipts reported by consumers; includes synthetic concentrates and other miscellaneous materials, after deduction of reshipments.

**TABLE 7
COLUMBIUM AND TANTALUM MATERIALS IN GOVERNMENT
INVENTORIES AS OF DECEMBER 31, 1991**

(Thousand kilograms of columbium or tantalum content)

Material	Stockpile goals	National Defense Stockpile inventory		
		Stockpile grade	Nonstockpile grade	Total
Columbium:				
Concentrates	6,019	522	394	¹ 916
Carbide powder	45	10	—	10
Ferrocolumbium	—	271	151	¹ 422
Metal	—	20	—	¹ 20
Total	(²)	823	545	1,368
Tantalum:				
Minerals	3,810	765	—	¹ 1,288
Carbide powder	—	13	(⁴)	¹ 13
Metal	—	91	—	¹ 91
Total	(²)	869	523	1,392

¹All surplus ferrocolumbium and columbium metal were used to offset columbium concentrates shortfall. Total offset was 520,700 kilograms.

²Overall goals, on a recoverable basis, total 5,679,100 kilograms for the columbium metal group and 3,247,800 kilograms for the tantalum metal group.

³All surplus tantalum carbide powder and tantalum metal were used to offset the tantalum minerals shortfall. Total offset was 122,900 kilograms.

⁴45 kilograms.

Source: Defense Logistics Agency, Defense National Stockpile Center.

**TABLE 8
MAJOR DOMESTIC COLUMBIUM AND TANTALUM PROCESSING AND PRODUCING COMPANIES IN 1991**

Company	Plant location	Products ¹						
		Metal ²		Carbide		Oxides and/or salts		FeCb and/or NiCb
		Cb	Ta	Cb	Ta	Cb	Ta	
Cabot Corp.	Boyertown, PA	X	X	—	—	X	X	—
Do.	Revere, PA	—	—	—	—	—	—	X
Kennametal Inc.	Latrobe, PA	—	—	X	X	—	—	—
NRC Inc. ³	Newton, MA	X	X	—	—	—	—	—
Reading Alloys Inc.	Robesonia, PA	—	—	—	—	—	—	X
Shieldalloy Metallurgical Corp.	Newfield, NJ	—	—	—	—	—	—	X
Teledyne: Teledyne Wah Chang Albany Div.	Albany, OR	X	—	—	—	X	—	X
Thai Tantalum Inc.	Gurnee, IL	—	X	—	—	—	—	—
Do.	Muskogee, OK	—	X	—	—	—	—	—

X Indicates processor and/or producer.

¹Cb, columbium; Ta, tantalum; FeCb, ferrocolumbium; NiCb, nickel columbium.

²Includes miscellaneous alloys.

³Jointly owned by Bayer U.S.A. and Hermann C. Starck Berlin KG.

TABLE 9
REPORTED SHIPMENTS OF COLUMBIUM AND TANTALUM
MATERIALS

(Kilograms of metal content)

Material	1989	1990	1991
Columbium products:			
Compounds, including alloys	450,686	NA	NA
Metal, including worked products	211,287	NA	NA
Other	—	NA	NA
Total	661,973	NA	NA
Tantalum products:			
Oxides and salts	3,293	NA	NA
Alloy additive	35,311	NA	NA
Carbide	NA	NA	NA
Powder and anodes	203,394	NA	NA
Ingot (unworked consolidated metal)	454	NA	NA
Mill products	124,831	NA	NA
Scrap	4,627	NA	NA
Other	—	NA	NA
Total	371,930	NA	NA

NA Not available.

Source: Tantalum Producers Association (TPA). Columbium and tantalum shipments were no longer available from the TPA. The TPA was dissolved in Dec. 1990.

TABLE 10
CONSUMPTION, BY END USE, AND INDUSTRY STOCKS OF
FERROCOLUMBIUM AND NICKEL COLUMBIUM
IN THE UNITED STATES

(Kilograms of contained columbium¹)

End use	1990	1991
Steel:		
Carbon	930,064	602,594
Stainless and heat-resisting	361,338	337,956
Full alloy	(2)	(2)
High-strength low-alloy	810,734	971,444
Electric	—	—
Tool	(2)	(2)
Unspecified	12,347	16,070
Total	2,114,483	1,928,064
Superalloys	454,822	462,519
Alloys (excluding alloy steels and superalloys)	(2)	(2)
Miscellaneous and unspecified	17,149	18,355
Total consumption	2,586,454	2,408,938
STOCKS		
December 31:		
Consumer	NA	NA
Producer ³	NA	NA
Total stocks⁴	NA	NA

¹Estimated. ²Revised. NA Not available.

³Includes columbium and tantalum in ferrotantalum-columbium, if any.

⁴Included with "Steel: High-strength low alloy."

⁵Included with "Steel: Unspecified."

⁶Included with "Miscellaneous and unspecified."

⁷Ferrocolumbium only.

TABLE 11
U.S. FOREIGN TRADE IN COLUMBIUM AND TANTALUM METAL AND ALLOYS, BY CLASS

(Thousand kilograms, gross weight, and thousand dollars)

Class	1990		1991		Principal destinations and sources, 1991
	Quantity	Value	Quantity	Value	
EXPORTS¹					
Columbium:					
Ores and concentrates	48	337	8	55	Mexico 6, \$34; Japan 1, \$8; India 1, \$7; Costa Rica (°), \$4; Canada (°), \$2.
Ferrocolumbium	585	5,495	741	6,952	Canada 649, \$6,144; Mexico 88, \$772; Trinidad and Tobago 2, \$19; China 1, \$14.
Tantalum:					
Synthetic concentrates	13	131	—	—	—
Ores and concentrates	1	7	11	248	Barbados 7, \$168; United Kingdom 3, \$70; Germany (°), \$10.
Unwrought and waste and scrap	89	3,862	121	3,651	Germany 114, \$3,111; Canada 3, \$281; United Kingdom 1, \$108; Austria 1, \$79; Netherlands 1, \$71.
Unwrought powders	82	21,638	66	19,659	United Kingdom 20, \$6,265; Japan 16, \$4,414; Germany 14, \$4,387; France 15, \$4,167; Italy 1, \$262.
Unwrought alloys and metal	12	3,700	21	4,336	Canada 15, \$3,380; Netherlands (°), \$279; Spain 2, \$270; Japan (°), \$172; United Kingdom (°), \$75; Mexico (°), \$75.
Wrought	60	20,068	77	26,580	Japan 39, \$13,330; Germany 9, \$3,657; United Kingdom 10, \$3,459; France 6, \$1,860; Canada 6, \$1,519; South Africa 3, \$1,324.
Total	XX	55,238	XX	61,481	Japan \$17,900; Canada \$11,300; Germany \$11,200; United Kingdom \$10,000; France \$6,000. ³
IMPORTS FOR CONSUMPTION					
Columbium:					
Ores and concentrates	2,251	7,898	2,515	8,445	Canada 2,241, \$7,598; Nigeria 64, \$253; Netherlands 51, \$167; Germany 37, \$164; Belgium 68, \$88.
Oxide	973	15,348	603	10,210	Brazil 521, \$7,951; Germany 82, \$2,253; United Kingdom (°), \$7.
Ferrocolumbium	2,919	24,685	3,282	27,415	All from Brazil.
Unwrought alloys, metal, and powders	2	149	1	103	Canada 1, \$66; Brazil 1, \$22; Germany (°), \$8.
Tantalum:					
Synthetic concentrates	51	1,464	63	741	All from Germany.
Ores and concentrates	1,016	25,589	937	19,868	Germany 296, \$5,653; Australia 113, \$4,360; Canada 133, \$3,458; Japan 78, \$1,496; Zaire 48, \$901; Thailand 40, \$861.
Unwrought waste and scrap	77	6,990	120	8,558	Germany 37, \$4,344; Japan 28, \$2,296; France 16, \$781; Mexico 27, \$381; China 4, \$292; United Kingdom 3, \$185; India 1, \$106.
Unwrought powders	13	2,038	16	2,645	Germany 10, \$1,561; Japan 2, \$695; China 3, \$388; Peru (°), \$2.
Unwrought alloys and metal	6	733	1	259	Germany 1, \$242; Japan (°), \$13; United Kingdom (°), \$4.
Wrought	3	1,028	2	765	Germany 1, \$572; Japan (°), \$54; Canada (°), \$54; Austria (°), \$30; United Kingdom (°), \$28; Switzerland (°), \$22.
Total	XX	85,922	XX	79,009	Brazil \$35,800; Germany \$15,500; Canada \$11,200; Japan \$4,600; Australia \$4,400. ³

¹Revised. XX Not applicable.

²For columbium, data on exports of metal and alloys in unwrought and wrought form, including waste and scrap, are not available; included in nonspecific tariff classifications.

³Less than 1/2 unit.

⁴Rounded.

Sources: Bureau of the Census and U.S. Bureau of Mines.

TABLE 12
U.S. IMPORTS FOR CONSUMPTION OF COLUMBIUM MINERAL
CONCENTRATES, BY COUNTRY

(Thousand kilograms and thousand dollars)

Country	1990		1991	
	Gross weight	Value	Gross weight	Value
Belgium ¹	—	—	68	88
Brazil	24	91	(²)	2
Canada	2,222	7,787	2,241	7,598
Germany, ¹ Federal Republic of	—	—	37	164
Netherlands ¹	—	—	51	167
Nigeria	—	—	64	253
United Kingdom ¹	—	—	32	87
Zaire	5	20	22	87
Total³	2,251	7,898	2,515	8,445

¹Presumably country of transshipment rather than original source.

²Less than 1/2 unit.

³Data may not add to totals shown because of independent rounding.

Sources: Bureau of the Census and U.S. Bureau of Mines.

TABLE 13
U.S. IMPORTS FOR CONSUMPTION OF TANTALUM MINERAL CONCENTRATES, BY COUNTRY

(Thousand kilograms and thousand dollars)

Country	1990		1991	
	Gross weight	Value	Gross weight	Value
Australia	74	2,835	113	4,360
Austria ¹	—	—	2	248
Belgium ¹	42	886	—	—
Bolivia	2	38	8	240
Brazil	153	3,563	23	376
Burundi ¹	10	250	—	—
Canada	115	2,795	133	3,458
China	—	—	20	503
French Guiana	—	—	(²)	14
Germany ¹	490	11,985	296	5,653
Japan ¹	—	—	78	1,496
Malaysia	5	143	—	—
Namibia	—	—	13	79
Netherlands ¹	6	203	29	613
South Africa, Republic of	—	—	20	380
Spain	6	116	—	—
Thailand	18	490	40	861
United Kingdom ¹	(²)	19	(²)	2
Zaire	76	1,895	48	901
Zimbabwe	20	371	113	685
Total³	1,016	25,589	937	19,868

¹Presumably country of transshipment rather than original source.

²Less than 1/2 unit.

³Data may not add to totals shown because of independent rounding.

Sources: Bureau of the Census and U.S. Bureau of Mines.

TABLE 14
U.S. IMPORT DUTIES ON COLUMBIUM AND TANTALUM MATERIALS

Item	HTS No.	Rate of duty effective January 1, 1991	
		Most favored nation (MFN)	Non-MFN
Synthetic tantalum-columbium concentrates	2615.90.3000	Free	30.0% ad valorem.
Columbium ores and concentrates	2615.90.6030	do.	Free.
Tantalum ores and concentrates	2615.90.6060	do.	Do.
Columbium oxide	2825.90.1500	3.7% ad valorem ^{1 2 3}	25.0% ad valorem.
Tantalum oxide	2825.90.6090 ⁴	3.7% ad valorem ^{1 3}	Do.
Potassium fluotantalate	2826.90.0000 ⁴	3.1% ad valorem ^{1 5}	Do.
Ferrocolumbium	7202.93.0000	5.0% ad valorem ^{6 7}	Do.
Unwrought tantalum waste and scrap	8103.10.3000	Free	Free.
Unwrought tantalum powders	8103.10.6030	3.7% ad valorem ^{1 3}	25.0% ad valorem.
Unwrought tantalum alloys and metal	8103.10.6090	do.	Do.
Wrought tantalum	8103.90.0000	5.5% ad valorem ^{1 8}	45.0% ad valorem.
Unwrought columbium waste and scrap	8112.91.0500 ⁴	Free	Free.
Unwrought columbium alloys, metal, and powders	8112.91.4000	4.9% ad valorem ^{6 9}	25.0% ad valorem.
Wrought columbium	8112.99.0000 ⁴	5.5% ad valorem ^{1 8}	45.0% ad valorem.

¹Free from certain beneficiary countries under the Generalized System of Preferences (GSP), from beneficiary countries under the Caribbean Basin Economic Recovery Act (CBERA), and for products of Israel.

²Not duty free for Brazil.

³1.4% ad valorem for products of Canada.

⁴Nonspecific tariff classification.

⁵1.2% ad valorem for products of Canada.

⁶Free from beneficiary countries under the CBERA and for products of Israel.

⁷2% ad valorem for products of Canada.

⁸2.2% ad valorem for products of Canada.

⁹1.9% ad valorem for products of Canada.

TABLE 15
PRINCIPAL WORLD COLUMBIUM AND TANTALUM RAW MATERIAL PRODUCERS

Country	Company and/or mine	Material type
MINING OF COLUMBIUM- AND TANTALUM-BEARING ORES		
Australia	Gwalia Consolidated Ltd. (Greenbushes) Pan West Tantalum Pty. Ltd. (Wodgina)	Columbium-tantalum. Tantalum.
Brazil	Cia. Brasileira de Metalurgia e Mineração (CBMM) (Araxá) Cia. de Estanho Minas Brasil (MIBRA) ¹ Parapanema S.A. Mineração Indústria e Construção (Pitinga) Mineração Catalão de Goiás S.A. (Catalão)	Columbium. Columbium-tantalum. Columbium-tantalum. Columbium.
Canada	Cambior/Teck Corp. (Niobec) Tantalum Mining Corp. of Canada Ltd. (Tanco)	Columbium-tantalum. Tantalum.
China	Government-owned	Columbium-tantalum.
U.S.S.R.	Government-owned	Columbium-tantalum.
Zaire	Société Minière du Kivu (SOMIKIVU) ¹	Columbium.
PRODUCTION OF COLUMBIUM- AND TANTALUM-BEARING TIN SLAGS		
Australia	Gwalia Consolidated Ltd. (Greenbushes)	
Brazil	Cia. Industrial Fluminense ¹ Mamoré Mineração e Metalurgia ²	
Malaysia	Malaysia Smelting Corp. Sdn. Bhd.	
Thailand	Thailand Smelting and Refining Co. Ltd. (Thaisarco).	
PRODUCTION OF COLUMBIUM- AND TANTALUM-BEARING SYNTHETIC CONCENTRATES		
Germany:		
Western states:	Gesellschaft Für Elektrometallurgie mbh (GFE) ¹ Hermann C. Starck Berlin KG	

¹A wholly owned subsidiary of Metallurg Inc., New York.

²A subsidiary of Parapanema S.A. Mineração Indústria e Construção.

TABLE 16
**PRINCIPAL WORLD PRODUCERS OF COLUMBIUM AND TANTALUM
 PRODUCTS**

Country	Company	Products ¹
Australia	Gwalia Consolidated Ltd. (Greenbushes)	Cb and Ta oxide.
Austria	Treibacher Chemische Werke AG	Cb and Ta oxide/carbide, FeCb, NiCb.
Brazil	Cia. Brasileira de Metalurgia e Mineração (CBMM)	Cb oxide/metal, FeCb, NiCb.
	Cia. Industrial Fluminense ²	Cb and Ta oxide.
	Mineração Catalão de Goiás S.A. (Catalão)	FeCb.
Germany:		
Western states	Gesellschaft Fur Elektrometallurgie mbH (GFE) ²	Cb and Ta oxide/metal, K-Salt, FeCb, NiCb, Ta capacitor powder.
	Herman C. Starck Berlin KG	Cb and Ta oxide/metal/ carbide, K-salt, FeCb, NiCb, Ta capacitor powder.
Japan	Awamura Metal Industry Co. Ltd.	FeCb.
	Japan Metals & Chemicals Co. Ltd.	FeCb.
	Mitsui Mining & Smelting Co.	Cb and Ta oxide/metal/ carbide.
	Showa Cabot Supermetals ³	Ta capacitor powder.
	Taiyo Mining & Industrial Co. Ltd.	FeCb.
	V Tech ⁴	Ta capacitor powder.
United Kingdom	London & Scadinavian Metallurgical Co. Ltd. ²	Cb and Ta carbide.
United States	Cabot Corp.	Cb and Ta oxide/metal, K-Salt, FeCb, NiCb, Ta capacitor powder.
	Kennametal, Inc.	Cb and Ta carbide.
	NRC, Inc. ³	Cb and Ta metal, Ta capacitor powder.
	Reading Alloys, Inc.	FeCb, NiCb.
	Shieldalloy Metallurgical Corp. ²	FeCb, NiCb.
	Teledyne Wah Chang Albany	Cb oxide/metal, FeCb, NiCb.
	Thai Tantalum Inc.	Ta metal.

¹Cb, columbium; Ta, tantalum; FeCb, ferrocolumbium; NiCb, nickel columbium; K-salt, potassium fluorotantalate; oxide, pentoxide.

²A wholly owned subsidiary of Metallurg Inc., New York.

³A joint venture between Showa Denko and Cabot Corp.

⁴A subsidiary of Hermann C. Starck Berlin KG.

⁵Jointly owned by Bayer U.S.A. Inc. and Hermann C. Starck Berlin KG.

TABLE 17
WORLD COLUMBIUM AND TANTALUM ANNUAL PRODUCTION
CAPACITY, DECEMBER 31, 1991

(Thousand kilograms of columbium or tantalum content)

Country	Rated capacity ^{1 2}	
	Columbium	Tantalum
North America:		
Canada	2,500	100
United States	—	—
Total	2,500	100
South America: Brazil	18,100	150
Africa:		
Nigeria	100	25
Zaire	500	25
Other	90	90
Total	690	140
Asia:		
Malaysia	90	90
Thailand	270	360
Total	360	450
Oceania: Australia	90	250
World total	21,740	1,090

¹Includes capacity at operating facilities as well as facilities on standby basis.

²Includes estimated byproduct recovery as tin slag.

TABLE 18
**COLUMBIUM AND TANTALUM: WORLD PRODUCTION OF MINERAL CONCENTRATES,
 BY COUNTRY¹**

(Thousand kilograms)

Country ²	Gross weight ³					Columbium content ⁴					Tantalum content ⁴				
	1987	1988	1989	1990	1991 ⁵	1987	1988	1989	1990	1991	1987	1988	1989	1990	1991
Australia: Columbium-tantalite	159	226	555	529	703	27	32	64	69	74	52	74	119	165	218
Brazil:															
Columbite-tantalite	447	403	436	310	290	103	93	101	71	66	130	117	126	90	84
Pyrochlore	17,116	33,814	26,329	24,623	25,853	7,189	14,202	11,058	10,342	10,859	—	—	—	—	—
Canada: ⁶															
Pyrochlore	4,304	5,230	5,443	5,272	5,230	1,937	2,354	2,449	2,372	2,354	—	—	—	—	—
Tantalite	—	91	295	331	399	—	4	9	10	11	—	27	73	82	95
Malaysia: Columbium-tantalite	228	—	—	4	5	34	—	—	1	—	16	—	—	—	—
Namibia: Tantalite	14	7	6	2	—	1	1	1	—	—	2	1	1	—	—
Nigeria: Columbium-tantalite	48	50	46	44	44	20	21	19	18	19	3	3	3	2	2
Rwanda: Columbium-tantalite	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
South Africa, Republic of:															
Columbite-tantalite	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Spain: Tantalite	10	11	11	10	8	NA	NA	NA	NA	NA	3	3	3	3	3
Thailand: Columbium-tantalite	183	124	109	9	3	31	21	19	2	1	49	33	29	2	1
Zaire:															
Columbite-tantalite	50	34	48	36	30	13	9	12	9	8	14	9	13	10	8
Pyrochlore	—	287	711	900	1,000	—	130	320	400	450	—	—	—	—	—
Zimbabwe:															
Columbite tantalite	37	66	32	33	33	3	10	5	5	5	6	23	11	12	12
Total⁷	22,595	40,342	34,021	32,103	33,359	9,358	16,876	14,056	13,298	13,847	275	291	378	366	423

¹Estimated. Revised. NA Not available.

²Excludes columbium- and tantalum-bearing tin concentrates and slags. Production of tantalum contained in tin slags was, in thousand kilograms: 1987—246; 1988—519; 1989—362; 1990—343; and 1991—244 according to data from the Tantalum-Niobium International Study Center. Table includes data available through July 2, 1992.

³In addition to the countries listed, Bolivia, China, the U.S.S.R., and Zambia also produce, or are believed to produce, columbium and tantalum mineral concentrates, but available information is inadequate to make reliable estimates of output levels.

⁴Data on gross weight generally have been presented as reported in official sources of the respective countries, divided into concentrates of columbite, tantalite, and pyrochlore where information is available to do so, and reported in groups such as columbite and tantalite where it is not.

⁵Unless otherwise specified, data presented for metal content are U.S. Bureau of Mines estimates based on, in most part, reported gross weight and/or pentoxide content.

⁶Reported in and/or by official country sources.

⁷Less than 1/2 unit.

Data may not add to totals shown because of independent rounding.

TABLE 19
COLUMBIUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand kilograms columbium content)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991 ^P
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mine production	(¹)	(¹)	—	—	—	—	—	—	(¹)	(¹)	(¹)
Shipments of Government stockpile excesses	—	—	—	—	—	—	—	—	—	—	—
Imports ²	3,611	*1,975	W	W	W	W	W	NA	NA	NA	NA
Industry stocks, Jan. 1	3,892	3,779	W	W	W	W	W	NA	NA	NA	NA
Total U.S. supply	7,503	5,754	W	W	W	W	W	NA	NA	NA	NA
Distribution of U.S. supply:											
Industry stocks, Dec. 31	3,779	*2,708	W	W	W	W	W	NA	NA	NA	NA
Exports ²	41	40	35	36	35	33	39	45	104	*227	270
Government accessions	—	12	—	—	97	—	—	—	—	—	—
Industrial demand	3,683	2,994	2,608	3,479	3,425	3,203	3,311	3,583	3,403	3,357	3,311
U.S. DEMAND PATTERN											
Construction	1,436	1,227	1,043	1,324	1,506	1,411	1,424	1,683	1,701	1,678	NA
Machinery:											
Metalworking machinery	129	97	78	104	103	96	90	90	82	82	NA
Special industry machinery	387	292	235	279	274	256	277	268	254	254	NA
Total	516	389	313	383	377	352	367	358	336	336	NA
Oil and gas industries	737	509	339	485	513	417	431	358	445	436	NA
Transportation	736	689	678	903	857	767	694	789	649	635	NA
Other	258	180	235	384	172	256	395	395	272	272	NA
Total U.S. primary demand	3,683	2,994	2,608	3,479	3,425	3,203	3,311	3,583	3,403	3,357	3,311

¹Estimated. ²Preliminary. *Revised. NA Not available. W Withheld to avoid disclosing company proprietary data.

¹A small unreported quantity was produced.

²Includes concentrates, ferrocolumbium, tin slags, and other.

TABLE 20
TANTALUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand kilograms tantalum content)

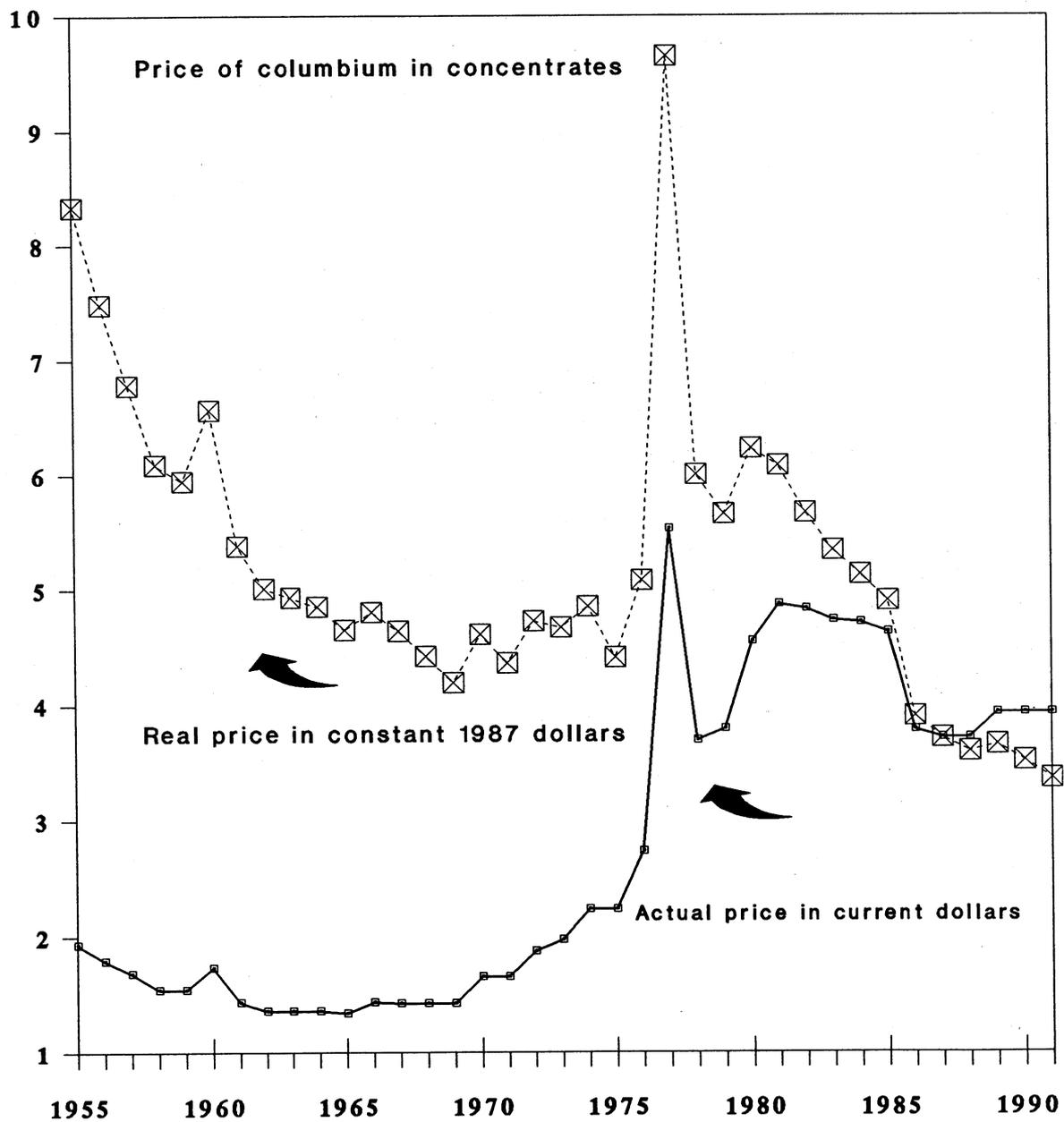
	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991 ^P
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mine production	(¹)	(¹)	—	—	—	—	—	—	(¹)	(¹)	(¹)
Secondary ^a	43	40	18	59	41	34	57	59	54	54	50
Shipments of Government stockpile excesses	—	—	—	—	—	—	—	—	—	—	—
Imports ²	717	*493	W	W	W	W	W	NA	NA	NA	NA
Industry stocks, Jan. 1	1,479	1,566	W	W	W	W	W	NA	NA	NA	NA
Total U.S. supply	2,239	2,099	W	W	W	W	W	NA	NA	NA	NA
Distribution of U.S. supply:											
Industry stocks, Dec. 31	1,566	*1,449	W	W	W	W	W	NA	NA	NA	NA
Exports ^a	101	154	119	174	145	142	171	256	195	*200	180
Government accessions	—	15	—	—	115	—	—	—	—	—	—
Industrial demand	572	481	536	762	363	372	381	422	376	390	370
U.S. DEMAND PATTERN											
Electronic components	400	319	333	477	201	219	229	277	227	236	NA
Transportation	46	55	75	99	60	56	57	32	54	59	NA
Machinery:											
Chemical equipment	38	31	21	27	22	20	15	14	14	14	NA
Metalworking machinery	87	63	86	120	46	51	27	27	27	27	NA
Total	125	94	107	147	68	71	42	41	41	41	NA
Other	1	13	21	39	34	26	53	72	54	54	NA
Total demand	572	481	536	762	363	372	381	422	376	390	370
Total U.S. primary demand (industrial demand less secondary)	529	441	518	703	322	338	324	363	322	336	320

^aEstimated. ^PPreliminary. ^RRevised. NA Not available. W Withheld to avoid disclosing company proprietary data.

¹A small unreported quantity was produced.

²Includes concentrates, tin slag, and other.

FIGURE 1
TIME-PRICE RELATIONSHIP FOR COLUMBIUM



—□— Actual price -□- Based on 1987 \$

Dollars per pound of columbium content

FIGURE 2
TIME-PRICE RELATIONSHIP FOR TANTALUM

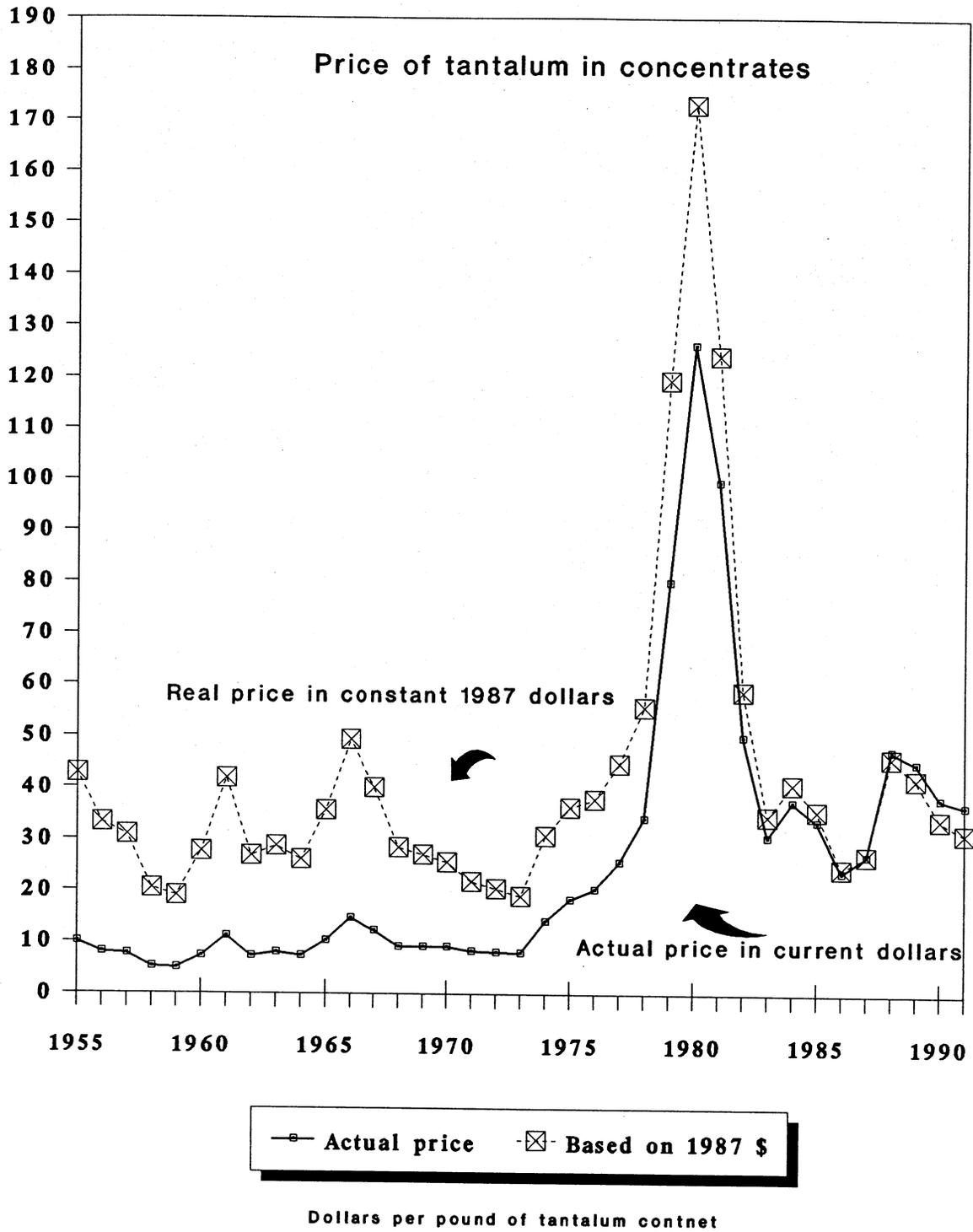
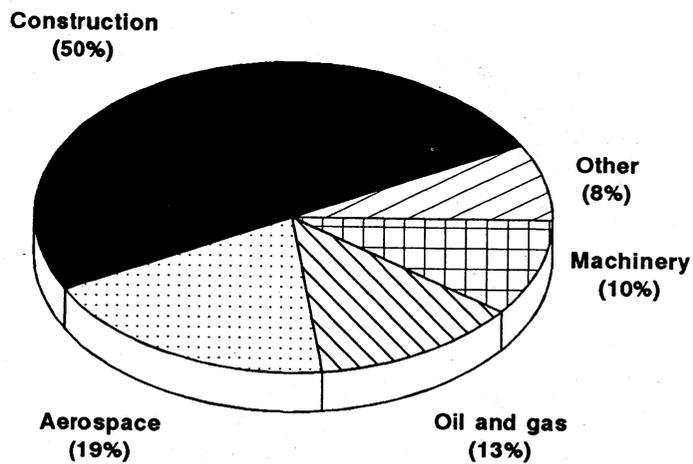
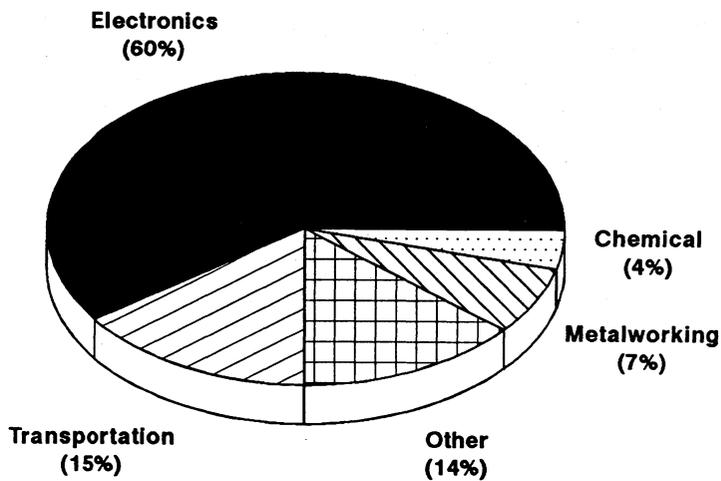


FIGURE 3
U.S. COLUMBIUM END USE IN 1990



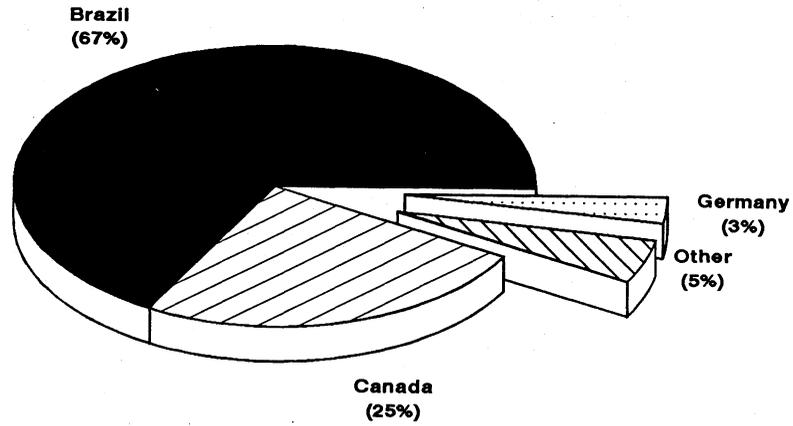
3.4 million kilograms

FIGURE 4
U.S. TANTALUM END USE IN 1990

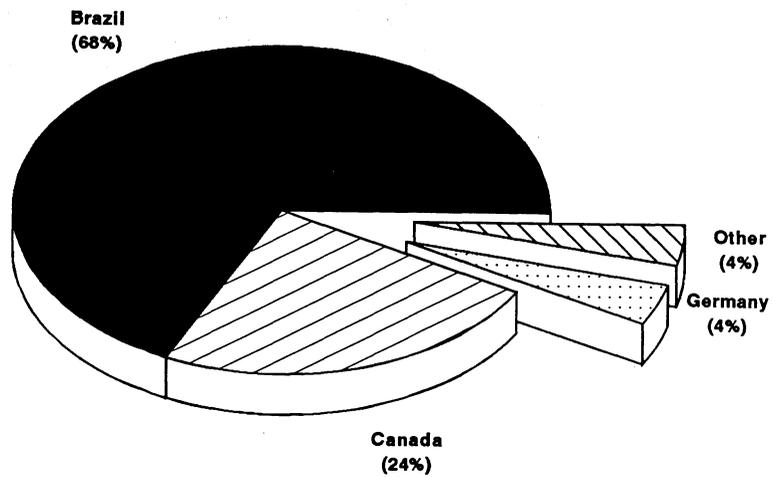


390,000 kilograms

FIGURE 5
MAJOR SOURCES OF U.S. COLUMBIUM IMPORTS



1991



1988-91

FIGURE 6
MAJOR SOURCES OF U.S. TANTALUM IMPORTS

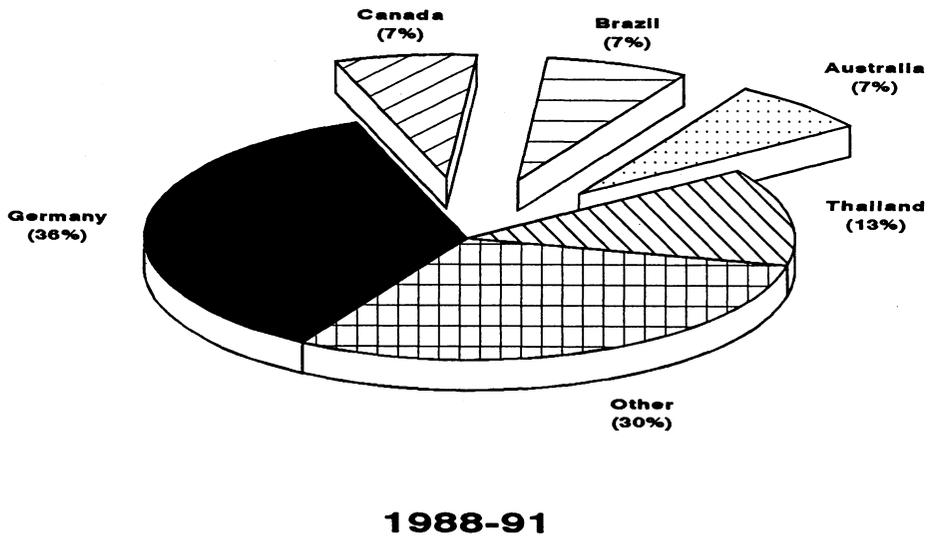
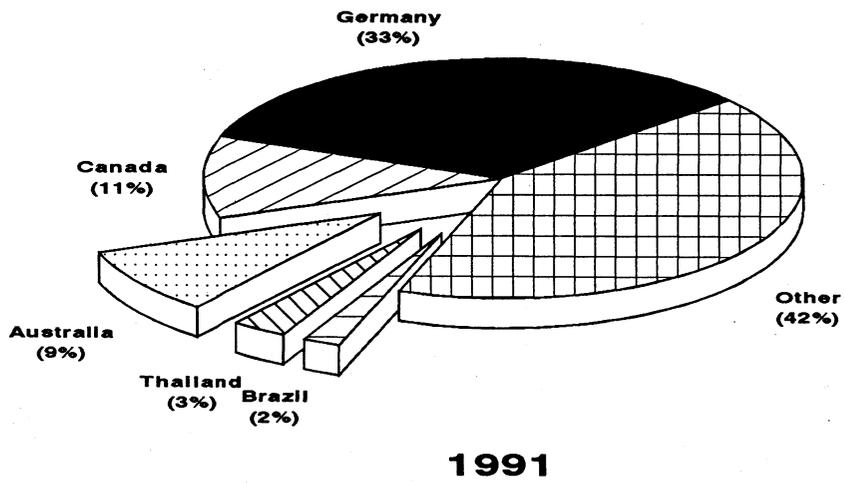
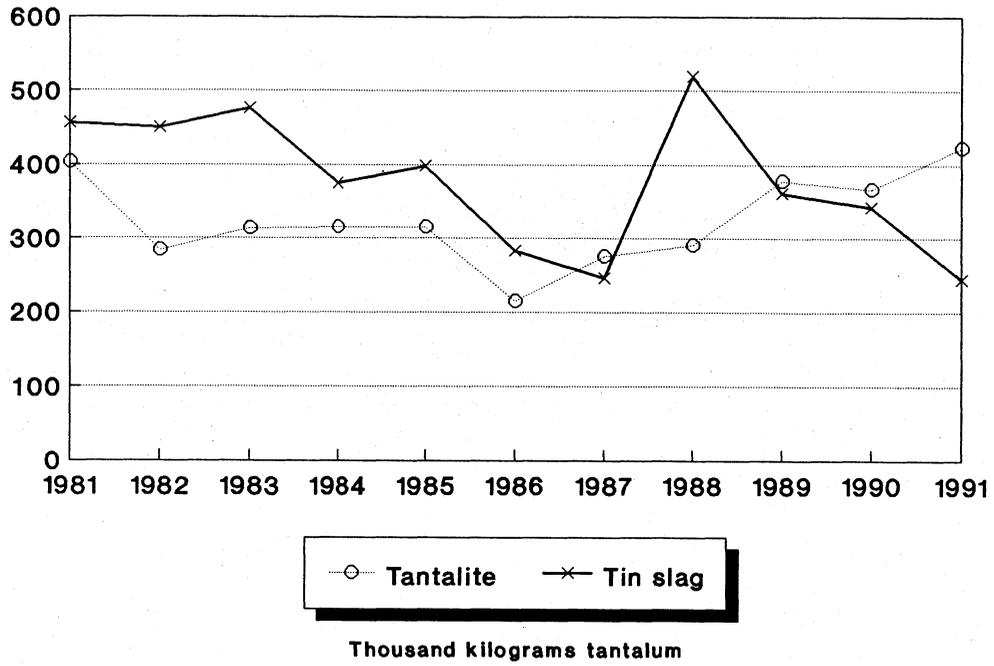


FIGURE 7
WORLD TANTALUM SUPPLY



COPPER

By Janice L. W. Jolly

Mrs. Jolly is a physical scientist (geologist) with more than 30 years in the mining industry, including 18 years with the U.S. Bureau of Mines. She worked as a research geologist on mineral deposits with the U.S. Geological Survey and Roan Selection Trust, Ltd. of Zambia and as a consultant on mineral affairs with the U.S. House of Representatives Armed Services Committee and the World Bank. Mrs. Jolly is currently the copper specialist for the U.S. Bureau of Mines, a position she has held since 1983. Domestic survey data were prepared by Lisa Conley, Lisa Christian, Marleese Collins, and Wannette Davis, mineral data assistants, and Jean Moore, data controller. The world production tables were prepared by country and data specialists in the Division of International Minerals.

World copper mine production of 8.8 million metric tons¹ and refined consumption of 10.8 million tons were at record levels in 1991. Though world copper supply and demand was in balance most of the year, the year ended with a surplus and an increase in refined stocks. Copper demand by U.S. semifacturers was lower during the first half of the year, but by yearend had increased as domestic markets recovered. Increased world demand continued to be driven by increased consumption in the Asian countries. Increased supplies from new capacity in Chile, Indonesia, Portugal, and the United States were offset by disruptions at other sources and the continued closure of the Bougainville Mine, Papua New Guinea. Production disruptions caused by mine closures, political problems, industry deterioration, and sporadic labor disputes also restrained the flow of copper. In addition, localized smelter shortages developed that were to both constrain refined production and increase processing charges for smelting and refining to record heights. At yearend, visible world refined inventories increased to an estimated 969,000 tons, an increase of 42% over that of 1990 and equivalent to about 5.6 weeks of market economy countries (MEC) consumption. As a result of the softer market, the U.S. producers' average annual price, at \$1.09 per pound, was lower than that of 1990. U.S. exports of scrap, concentrates, and refined copper continued to be high; most

were destined for Far Eastern markets in China, Japan, South Korea, and Taiwan.

DOMESTIC DATA COVERAGE

Domestic production data for copper were developed by the U.S. Bureau of Mines from seven separate surveys of U.S. operations. Typical of these surveys is the mine production survey. Of 123 operations to which a survey request was sent in 1991, 93% responded and 74 reported copper production, representing an estimated 99.8% of the mine production shown in tables 1, 12, 14, and 15. Production for the remainder was estimated using other surveys.

BACKGROUND

Definitions, Grades, and Specifications

Copper is traded in many forms that relate to differing stages of processing. For example, at the mine, copper may be sold as ore, concentrates, or precipitates. *Copper ore* may contain as little as 0.40% copper or more than 10% copper, depending on its source. *Copper concentrates* are produced by milling and concentrating copper ore and may contain between 18% and 40% copper. *Copper precipitate, or cement copper*, is recovered from leach solutions by chemical precipitation with scrap iron and may contain as much as 90% copper.

Smelter products include *copper matte, blister, slag, and anode*. *Slag* is the waste formed in smelting through the

combination of a *flux*, such as limestone and silica, with the gangue or waste portion of the ore and, though it may contain small amounts of copper, is high in silicon and iron. *Copper matte* contains between 15% and 65% copper, together with much of the sulfur and other nonferrous and precious metals. The newer flash smelting technologies result in a much lower sulfur content in the matte than was possible in reverberatory furnaces. Copper matte is transferred to a converting furnace where the sulfur and iron are oxidized and removed as sulfur dioxide gas and slag, respectively; the enriched copper melt (97% to 98.5% copper) is poured as *blister copper*. The blister is then *fire refined* by oxidizing the impurities in a reverberatory furnace, followed by removal of the excess oxygen by a process called *poling*. Poling may be done by insertion of green logs or a reducing gas into the melt. The blister is then cast into *anode* shape and further treated in an electrolyte bath to form *refined copper cathode* through electrolysis, a process in which the copper ions of the anode are transferred by electrical current to the negatively charged cathode. Impurities in the copper anode, such as gold, selenium, and silver, are collected at the bottom of the electrolytic tank as a residue and are recovered in a later process. Cathode copper also may be obtained from an *electrowinning* process. In this process, cathode copper is plated directly from copper-bearing solutions obtained from

leaching copper-bearing ore, matte, scrap, or other material and enriched by solvent extraction methods. Alternatively, *fire-refined* copper, or scrap, may be cast into ingots, bars, billets, or cakes and not processed electrolytically in a refining tank before direct use.

Refined copper cathode, which contains greater than 99.3% copper, is the predominant form traded. *Tough-pitch copper* is refined copper cast into shapes. *Oxygen-free copper*, which is preferred for special electrical uses, is refined copper melted and recast in a deoxidizing atmosphere. *Deoxidized copper* is refined copper treated with deoxidizers to reduce cuprous oxide and remove oxygen. Normal refinery shapes cast from cathodes and fire-refined copper are wirebars, billets, slabs, ingots, and bars. Since the late 1970's, the *continuous cast wire rod* has almost eliminated the wirebar as an intermediate shape used for making wire rod from refined copper. *Wire rod* is used to make wire. *Wirebar* currently comprises less than 1% of the copper market. *Billets* typically are large cylindrical shapes often used for extruding tubing, or sometimes wire rod. *Slabs* are the precursors to flat products such as sheet. *Ingots* are small shapes that are usually remelted and used for making alloys.

There are more than 370 copper and copper alloys divided into broad categories of wrought and cast metals. A Unified Numbering System (UNS) for Metals and Materials was developed by the American Society for Testing and Materials (ASTM) and the Society of Automotive Engineers. This system designates each copper alloy by five digits preceded by the letter C. The UNS system is administered by the Copper Development Association (CDA) and is widely used by ingotmakers, brass mills, and foundries in the United States. The five major classes are *coppers*, which contain greater than 99.3% copper; *high-copper* alloys, which contain at least 94% copper; *brasses*, which contain zinc as the dominant alloying agent; *bronzes*, which normally contain tin as the

dominant alloying agent, but also may contain such other metals as aluminum, lead, phosphorus, and silicon, but only small amounts of zinc; *copper-nickels*, which contain nickel as the principal alloy metal; *nickel silver*, which contains copper, nickel, and zinc as the principal metals; *leaded coppers*, which are cast alloys containing 20% or more of lead, but no zinc or tin; and *special alloys*, which are copper alloys with compositions not covered in the aforementioned groups. *Master alloys* and *hardeners* are copper-base alloys cast with a high alloying element content and are used in producing copper alloys. Hardeners and master alloys not only permit closer composition control than is possible by addition of pure metals, but also permit easier introduction of a deoxidizer, such as phosphorus. Beryllium copper master alloy, containing 7% to 10% beryllium, and phosphor copper, containing 10% to 14% phosphorus, are examples. The ASTM specifications for refined copper are designated in part 6, section B5-77 of the ASTM specifications and are under the jurisdiction of ASTM Committee B-5 on copper and copper alloys.

Industry Structure

Mine Production and Concentrate Trade.—Copper was mined in 53 countries, with the top 14 producing nations in the MEC accounting for almost 73% of world production. Almost 7 million tons was mined in the MEC with the largest contributors, Chile and the United States, comprising 54% of the top 14 producers. To the world's total mine production, the United States and Chile contribute 18.5% and 21%, respectively.

Most copper mine producers export some concentrates to other countries for processing, but the amount available for export varies considerably among producers. The largest concentrate exporters are, as shown in figure 1, Australia, Canada, Chile, Indonesia, Papua New Guinea, and the United States. (See figure 1.)

Only 20% of copper in concentrates produced was available for trade with other countries. The availability of concentrates for the world's smelting and refining countries has varied over time, owing to many factors such as transportation costs, the impact of the U.S. mine curtailment during the 1970's and 1980's, and the development of new smelting and refining capacity in mine-producing countries such as Chile, Peru, and the Philippines. The largest concentrate exporters in 1991 were Canada (17.8%), Chile (28.4%), the United States (14%), Indonesia (6.4%), and Portugal (9.8%). The United States has become a significant exporter of concentrates since the late 1980's, owing to its renewed position as a dominant mine producer as well as to its insufficient domestic smelter capacity. The African countries Zaire and Zambia did not export much in the form of concentrates largely because of their landlocked position, higher expense for bulk transport, and availability of cheap power for processing plants. These countries also consumed very little of their refined or blister copper, and so were large exporters of refined copper. The Republic of South Africa also exported crude copper, but consumed as much refined copper as it exported. The largest concentrate importers were Japan (61%), Germany (8.6%), South Korea (7.1%), Spain (7.6%), and Finland (5%).²

Refined Copper Production and Trade.—Historically, the largest smelters and refiners have been in or near the large refined copper-consuming industrialized countries to support their manufacturing industries. Figure 2 shows the dominance of the industrialized countries of North America and Europe as refined copper producers. Since 1971, as shown on figure 3, several Asian and South American countries have been increasing their refined production capacity. (See figures 2 and 3.)

In South America, the largest refined copper producer is Chile. In fact, CODELCO-Chile, the Government-owned copper producer, is the largest

refining company in the world. Australia also has been developing its refined copper industry in recent years. The largest refined copper producer in Asia was Japan, followed by a rapidly growing China. The copper industry of central Africa, because of its isolated location, size of the mine production, and energy availability, developed smelting and refining facilities early in its development. Elsewhere, with cheaper ocean transportation and lacking energy resources necessary for economic operation of a smelter and refinery, many mine-producing countries initially opted not to develop downstream processing. This was further promoted by industrialized countries with poor copper mine resources, which traditionally invested heavily in mine development in other countries to ensure long-term concentrate supplies. This resulted in significant Japanese and European ownership of the world's copper mines and smelters.

Refined copper, in its various forms, was an internationally traded commodity sold through producer contracts or spot market sales through the commodity exchanges of New York and London. Figure 4 compares the dominant refined-copper-producing areas with exports in 1991. It was significant that only 34% of the world's refined copper production was exported to the world's markets. Refined copper from South America comprised almost 33% of the world's refined copper exports, whereas Europe and North America made up more than 60% of the total production. Zambia (389,000 tons) was the second largest refined copper exporter after Chile (1.1 million tons). Copper rod was also a dominant form traded within countries such as the United States, where almost 60% of the copper mined and refined was used for rod. Trade in rod had been increasing in recent years, but long-distance transport of this product had been hampered by quality problems. New continuous-cast rod plants were constructed recently in many newly industrialized countries, largely for use in their economies. Following the need for expanded electrical facilities in these

countries, this was an area of significant growth for the future. The world's largest refined copper importers in 1991 were as follows:³ Japan (16.8%), Germany (15%), France (11.8%), Italy (11%), Taiwan (10.7%), the United States (8%), Belgium (6.4%), and the United Kingdom (6.5%). (See figure 4.)

Refined Copper Consumption.— Refined copper consumption statistics were measured at the first fabrication stage. That is, they represented refined copper consumption by rod mills, brass mills, foundries, chemical plants, and other miscellaneous manufacturers. Recognition of this fact is important largely because these statistics have been misrepresented in intensity of use studies. Consumption trends associated with comparative statistics, such as gross national product (GNP) and other economic dollar-valued indicators, have been misinterpreted as an indication of a society's consumption habits, rather than as a measure of the Nation's industrial consumption. Contrarily, a recent University of Arizona study indicated that in the United States, copper "embodied" in net imports of manufactures had increased from about 200,000 tons in 1970 to 577,000 tons in 1985, and this amount should be added to the modest growth in copper consumed by U.S. semifabricators for a more complete measure of U.S. societal consumption trends.⁴

The largest refined copper-consuming nations have long been the industrialized countries with large manufacturing bases. The final products, such as automobiles containing copper radiators, are not necessarily consumed in the country of manufacture. The major copper-consuming countries or areas of the world in 1991 were Western Europe (29.2%), the United States (19.7%), Japan (15%), the U.S.S.R. (6.5%), and China (5.4%). An estimated 10.7 million tons of primary and secondary refined copper was consumed in 1991. Figure 5 illustrates the proportion of copper consumed among MEC. Europe and the United States consume about 60% of

MEC copper consumption. (See figure 5.)

The United States has been historically the largest copper-consuming nation in the world, consuming more than 50% of the world's copper until 1949, when the Asian and European nations began to increase their manufacturing bases. After 1950, the U.S. share of world copper consumption began to decline, as shown in figure 6, until 1975, when it stabilized at about 20% of the total. At the same time, U.S. per capita consumption stabilized at about 20 pounds per person over the 1950-91 period, indicating that the U.S. manufacturing base was able to keep pace with the growth in population despite the heavy influence of finished copper good imports such as automobiles and refrigeration units. Trends in per capita consumption from 1875 to 1990, as shown in figure 7, indicate three periods of growth as (1) the rapid electrification that took place in the late 1800's and early 1900's, (2) the pre-World War II period, and (3) the much higher level of copper consumption (20 pounds per person) that followed World War II. The new technologies that followed World War II required higher levels of electrical and electronic material consumption. (See figures 6 and 7.)

Since the 1960's, the trend has been toward increased consumption by the Asian countries, particularly Japan, South Korea, and Taiwan. More recently, China has built new rod and brass mills for its increased domestic copper needs. China imported 114,000 tons of refined copper in 1991, compared with only 40,000 tons in 1990 and 75,500 tons in 1987, and was a significant importer of copper scrap. In 1991, the Taiwan Government approved an \$8.2 billion construction project that included a new powerplant, requiring a significant increase in copper consumption. Taiwan imported 397,900 tons of refined copper in 1991, compared with 253,100 tons in 1990 and only 161,400 tons in 1987. The significant growth of copper consumption in the Asian and Western European countries since 1964 is shown in figure 8. Japan began its significant growth in the late 1960's, whereas

Taiwan and Korea started in the 1980's. India's refined copper consumption also was growing, and this was expected to increase by 51% to about 204,000 tons per year by 1995. India's needs have grown much more rapidly than its mine production so that it has become increasingly dependent on imports. (See figure 8.)

These trends were expected to continue with increased consumption growth in Eastern Europe and South America. Growth in the United States, Japan, and Canada was seen as proceeding at a much slower rate. Growth in Japan has stabilized in recent years, as it has in the United States.

History of Latin American Mining.—Early Latin American (Andean) copper mining was prompted by the need to develop symbolic objects that served political power, the display of social status, and communication of religious belief. Goldplated and alloyed copper objects were common in the pre-Inca Chavin culture of about 1000 B.C.⁵ Electrochemical replacement and depletion silvering or gilding on copper surfaces were devised in pre-Columbian times to give a precious-metal appearance. The first known Andean example of copper-silver alloy is a Peruvian bead from the Lurin valley site of Malposo. Tumbaga, a gold-copper alloy, was first produced in the central Andes, but later became common to many parts of pre-Columbian South America and as far north as Mexico. In 1494, Columbus reportedly initiated gold mining with a copper byproduct in the Dominican Republic. The Spanish Conquistadores valued copper for use in armaments.

The first European copper mine in Latin America opened in 1522 at Taxco, Mexico. Mexico produced a cumulative total of 8,000 tons of copper by 1890, and averaged about 65,000 tons annually by 1905 and more than 200,000 tons per year by the early 1970's.⁶ The most important Mexican deposits were at Cananea and Nacozari (La Caridad) in Sonora and, formerly, at El Boleo in Baja California.

The 19th century was a time of political turmoil in Chile, and copper mining became increasingly important. The Pacific War, involving Chile, Bolivia, and Peru (1879-83), resulted in the incorporation of the copper-rich Regions I and II into northern Chile. For many years, only the high-grade carbonates and oxides were worked, and the ore was smelted locally in primitive charcoal furnaces. Copper mining expanded in Chile following the introduction of the first reverberatory furnace to Chile in 1842, which permitted smelting of copper sulfide minerals. In 1857, the first blast furnace was installed. Chile became the foremost world producer until 1882, when the United States took the lead. From 1850 to about 1900, copper produced in Chile was practically all shipped to England under the influence of significant European investment. A new era for Chilean copper again evolved in the early 1900's through U.S. investment and mining technology. Using the U.S.-developed froth flotation for copper ore concentration and large-scale, open pit mining methods, low-grade Chilean copper porphyries could be exploited. The Chilean Cordillera possesses several great copper porphyry deposits, including early discoveries of Chuquicamata, El Salvador, Poterillos, Rio Blanco, and El Teniente and more recently, of La Escondida and La Candelaria. Chile's largest, the Chuquicamata Mine (600,000 tons per year), began large-scale production in 1912. La Escondida Mine (300,000 tons per year) started production in late 1990. The mostly U.S.-owned, large Chilean copper mines were nationalized on July 16, 1971. The Government-owned copper company, Corporacion Nacional del Cobre de Chile (CODELCO-Chile), into which the expropriated mines were incorporated, is the largest copper mining and refining company in the world. Chile once again became the world's largest copper mine producer in 1982, when it surpassed the United States. Chile's annual copper production in 1991 was more than 1.8 million tons of copper.

Peruvian production in recent years has been about 400,000 tons of copper per year, but its copper industry did not grow significantly until after the Pacific War, aided by the completion of the central railway, and again between 1940 and 1960, by the significant exploration and mining development efforts of U.S.-owned companies.⁷ Though significant reserves are known in the Carajas District of Brazil, mines of the Rio Grande do Sul area have been the most important, producing about 46,000 tons of copper per year. Copper also has been mined in Argentina, Bolivia, Colombia, Cuba, Ecuador, Guatemala, Haiti, Honduras, Nicaragua, Panama, and Venezuela, but although some countries have undeveloped resources, the amount mined has been small. Between 1800 and 1926, the copper mines in the Bolivian Province of Pacajes near the Chilean border had an annual production of about 20,000 tons per year of copper.⁸ Argentina, Bolivia, Ecuador, and Honduras currently produce less than 600 tons per year of copper each. Cuba has produced copper from the Pinar del Rio Province near Matahambre since the end of the 19th century. Copper has been mined near Caracas, Venezuela, and from deposits near the Port of Cabello, in the State of Yaracuy, since the early 16th century. Copper mining in Haiti began in 1728, and with development of the Meme Copper Deposit in the late 1950's, continued through 1971.

In 1991, the countries of Latin America contributed 28.9% of the world copper mine production of about 8.8 million tons and held 37% of the total world copper ore reserve base of 587 million tons of copper. Chile possessed 24%; Peru, 4%; and Mexico, 3% of the world's copper reserve base.

Geology

According to their mode of origin, copper deposits may be grouped in the following broad genetic classes: (1) porphyry copper deposits and their associated skarn, hydrothermal veins, and replacement breccia deposits; (2) deposits associated with ultramafic, mafic, and

alkaline ultrabasic and carbonatite rocks; (3) volcanogenic and metavolcanogenic deposits; (4) sedimentary and metasedimentary deposits; and (5) veins and replacement bodies associated with metamorphic sequences, not otherwise classified. As a percent of total world capacity, the predominant types mined were: the porphyry copper and associated deposits (59%), stratiform sedimentary replacement and metasedimentary deposits (24%), volcanogenic massive sulfide deposits (7%), veins and replacement bodies (7%), and ultrabasic massive sulfide and carbonatite deposits (4%). Though the massive sulfide and vein and replacement deposits were much more numerous than the porphyry and stratiform sedimentary deposits, they tended to be smaller in both capacity and reserves, but generally contain a wider variety of other mineral coproducts. In the United States, porphyry copper deposits comprised about 93% and stratiform sedimentary and metasedimentary deposits about 6% of established mine capacity.

In recent years, plate tectonic theory has been emphasized in defining copper deposits as they relate to the Earth's lithospheric plates, their edges, subduction zones, and spreading axes in space and time. For example, deposits of the porphyry copper type occur mainly in magmatic, volcanic arc, and back-arc regions of plates overlying subduction zones; hence, their predominant location along areas such as the continental edges of North and South America. Copper deposits found in ultramafic sequences are characteristic of oceanic plate settings and ophiolite rock groups. Alkaline ultrabasic rocks and carbonatites intrude stable continental cratons and are presumed to have come from mantle-derived magmas contaminated with crustal rocks. At Palabora, the Republic of South Africa, a carbonatite is host to a copper deposit; as a significant producer of copper, this is a unique occurrence. Sedimentary copper deposits generally occur in rocks typical of passive continental margin and interior environments, and intracontinental rift systems. In addition, these deposits may

have been redistributed by later diagenetic or metamorphic hydrothermal systems, but retain their stratiform identity. *Stratiform* applies to a layered mineral deposit of any origin. *Stratibound* refers to a deposit confined to a single stratigraphic horizon.

Copper occurs in about 250 minerals; however, only a few are commercially important. The most common are chalcopyrite (CuFeS_2), covellite (CuS), chalcocite (Cu_2S), bornite (Cu_5FeS_4), enargite (Cu_3AsS), and tetrahedrite ($3\text{Cu}_2\text{S}\text{-Sb}_2\text{S}_3$). Metals may be leached out of the rock above the water table by circulating ground water, oxidized, and enriched in the underlying supergene zone. The supergene capping of an ore body often contains the highest concentration of copper as chalcocite or as various copper oxide and silicate minerals. Native copper also occurs in the oxidized or supergene zones.

Technology

Exploration.—Exploration for copper deposits may take place in potential areas within which the anticipated copper deposit is masked by post-ore cover, such as alluvium, and volcanic or sedimentary rock. Following discovery of a potential deposit by geophysical and geochemical means, successive and increasingly intensive drilling campaigns to characterize and quantify the deposit are undertaken before a decision is made to bring a deposit into production. Continued drilling programs to extend identified reserves may continue throughout the production life of the deposit.

A mining company develops an inventory of exploration properties through ongoing exploration and acquisition programs. With further examination, these properties eventually become candidates for development. Economic conditions determine whether there is a hiatus at this stage or whether the property can move on to development. Taking a prospect through all stages to a producing mine is full of risks and requires complex analyses in

geology, metallurgy, engineering, and finance. Environmental considerations are also important in today's decision process.

Good geological concepts will lead an exploration team into a regional environment with the highest probability of economic discovery. In addition, before exploration or development occurs, political and economic factors also will be considered. These factors include the potential for expropriation, availability of land, ease of land acquisition, and local attitude of people toward mining, including environmental concerns. Economic factors include tax policy, transportation facilities, infrastructure power costs, availability of labor, development incentives, and environmental and reclamation requirements.

Copper exploration was seriously lacking through most of the 1970's and 1980's, not only owing to a lack of available funds, but also to an increasingly hostile public point of view about the need for mining. For at least two decades, the socioeconomic and political trends of the United States have been effective in preventing rapid exploration and development of new ore deposits. Creeping urbanism, a desire to preserve pristine wilderness areas, and prevention of environmental pollution have had effect on the success of companies in getting exploration and mining permits in the United States.

No old mining district is positively dead in a geologic sense; the next minor geologic revelation may bring it to life. Further elucidation of ore genesis theory could revolutionize exploration. Improved exploration techniques on the horizon include: improved spatial and spectral imagery resolution for penetration of foliage and surface cover; increased digital geophysical coverage of the United States (magnetically, gravitationally, radiometrically, and spectrally), and improved drilling, sampling, and analytical methods. Geosensing, with the ability to predict ore body variations, geological disturbances, and in situ ore grade variations, also can be improved.

Estimates have varied on the frequency of success for exploration programs. A rough ratio might be 1:100; i.e., that for every 1 ore body of any type, 100 raw prospects must be tested. Substantial ore bodies that are large enough to return exploration expenditures, and provide a profit, are much more scarce. The ratio for world-class deposits to all deposits has been estimated to be more like 1:1,000.⁹ World-class deposits have been defined as those that consistently returned a profit even in periods of low metal prices, that are of a significant magnitude to affect a medium-sized company's profit, and that are in the lower one-third of cost per unit of metal sold. Using this definition, it was estimated that in more than 30 years (720 combined corporate years) of effort only 69 world-class deposits were found. Using revised criteria relating to size and profitability; i.e., a deposit yielding more than \$500 million in revenue, the number of successful, large discoveries could be increased from 70 to 166 between 1950 and 1986.¹⁰ Though small in number, these world-class deposits currently provide almost 60% of the world's production of copper. There were only 32 mines with copper production capacity of greater than 100,000 tons per year in 1991.

Mining and Milling.—Since the turn of the century, the evolution of technology for large-scale mining, milling, and concentrating of low-grade ores has resulted in a continued shift away from mining small, high-grade, massive sulfide deposits by labor-intensive underground methods. Today, open pit mining accounts for 55% of world copper mine capacity and about 83% of domestic mine capacity. Open pit mining requires a shallow deposit with typical stripping, waste-to-ore, ratios between 1:1 and 2:1. A typical surface copper mine uses rotary blasthole drills and a shovel-truck combination for the loading and hauling operation. Underground mining methods vary with the physical nature of the ore and host rock, but typically have lower waste-to-ore ratios and higher grades and

employ some form of large-scale block-caving such as that employed at San Manuel in the United States and El Teniente in Chile. Following extraction, run-of-mine ore is crushed and ground to liberate the copper sulfide minerals and beneficiated or concentrated via froth flotation to produce a concentrate containing about 30% copper suitable for smelting.

Faced with higher energy costs, deeper mines with longer haul distances, high labor rates, and lower ore grades, the domestic industry has strived to maintain and/or lower production costs over the past few decades. Major improvements in energy use and labor management in mining and milling technology have been made in recent years through improved methods of materials transport, grinding, and concentration. Technological improvements include in-pit crushing and conveying systems to replace truck haulage to the mill; semiautogenous and autogenous grinding circuits; column and cyclone flotation cells; larger-scale equipment, including trucks and flotation cells; computer-controlled truck dispatch systems; and improved on-line sampling and automated reagent control in the mill. A microwave system for communications was being used by Phelps Dodge at the Morenci Mine. Microwave was chosen over cable because of the changing mining contour, the distances to be covered, and potential for equipment damage by lightning to the older systems. In mining, further improvements were anticipated in automated mining, nonexplosive rock fragmentation, and process and extraction technologies that result in minimal hazardous conditions. The clean plant concept (hazard free) should be built into design criteria.

An important factor in domestic mine cost savings has been the development and rapid expansion of solvent extraction-electrowinning (SX-EW) technology for the treatment of acid-soluble oxide or chalcocite ores. In this process, dilute sulfuric acid is percolated through the ore, either in dumps, pads, or in situ. The copper-bearing solution (leachate) is collected and processed by solvent extraction methods to concentrate the

copper, which then is recovered by electrowinning, plating copper directly from solution onto a starter cathode. The resultant pure copper cathode thus bypasses the traditional smelting and refining steps. Recent advances in the organic extractants and in electrowinning have improved the economics of this process. Mines have realized tremendous cost savings by processing oxidized ores, leaching existing waste and ore dumps and lower grade mined ore, and by adjusting cutoff grades to the concentrator upward. Growth in SX-EW capacity has been rapid since the mid-1970's. SX-EW capacity for the world, which was estimated to be about 1.1 million tons of copper per year in 1991, was expected to exceed 2 million tons by the year 2000. SX-EW capacity has been particularly significant in Chile, the United States, Zaire, and Zambia, where favorable oxides and leachable sulfide deposits are more common. In Chile, an ammonia leach (Arbiter) process is to be tried on La Escondida sulfide concentrates in a mine expansion project under consideration there.¹¹

History of SX-EW Production in the United States.—In the United States, SX-EW capacity increased from only 37,000 tons in 1974 to 460,000 tons of copper in 1991. Copper electrowon production at U.S. mines and refineries for the years 1968-91 is shown in table 2. In 1968, U.S. electrowinning production amounted to 10,123 tons and by 1991 had increased to 441,241 tons as companies moved to cut costs through what had become a low-cost alternative for producing copper from certain ores. U.S. electrowinning capacity was expected to peak at about 690,000 tons in 1998. Average production costs were said to be 20 to 45 cents per pound depending on whether mining costs were partially written off against normal mining or were a factor at all. This compared with an average mining, milling, smelting, and refining cost of 60 cents per pound of refined copper extracted through the normal process, as estimated for 1990. (See table 2.)

Electrowinning began in the United States at two mines in 1968, the Inspiration and Bluebird, and a third, the Ray Mine, in 1969. The Cyprus Minerals Co. Bagdad plant began in 1970, while other Arizona plants started later in the 1970's, including Anamax Co.'s Twin Buttes plant (1975), Cyprus Minerals' Johnson plant (1975), Hecla Mining Co.'s Casa Grande plant (1976), Duval Corp.'s Sierrita CLEAR-process plant (1979), and City Service Co.'s Miami plant (1978). The Anaconda Minerals Co.'s Arbiter, MT, plant began in 1974. Duval Corp.'s Battle Mountain, NV, plant began copper production in 1979. In the 1980's, several new plants were put in place beginning with Magma's Pinto Valley plant (1981), the Burro Chief plant at the Tyrone Mine (1984), Magma's San Manuel oxide (1986) and in situ operations (1988), the new Cyprus Minerals' Sierrita plant (1987), the Phelps Dodge Morenci plant (1987), and the Chino Mines Co. plant (1988) at the Santa Rita Mine in New Mexico. While expansions and renovations continued at several operating plants during the 1980's, some were shut permanently, including the Ranchers' Bluebird plant (1982), the Arbiter plant (1977), the Sierrita CLEAR-process plant (1982), and the Battle Mountain plant (1984). The Cyprus Johnson plant was closed in 1986 with plant and equipment sold, but Arimetco renewed production in 1990 with a new plant. Kennecott's Ray plant was to undergo several renovations as it moved to improve the quality of its output. Shut down in 1982, the Ray plant was renovated and reactivated by ASARCO Incorporated after it purchased the plant in 1984. The Duval Corp. CLEAR-process plant at Sierrita, which produced a high-grade precipitate, was never economical to operate, and a new SX-EW plant was constructed at the Sierrita Mine in 1987 to recover copper from heap-leached oxide ores. In the 1990's, expansions were made at all Phelps Dodge plants, Cyprus Minerals increased production at Bagdad and Lakeshore and renewed production at Twin Buttes, and Arizona Metals Co. (Arimetco) began production at its

Yerington, NV, and Johnson Camp, AZ, plants. Morenci was the largest SX-EW producer in the United States with more than 150,000 tons per year of capacity.

Most SX-EW solutions were derived from leaching processes that were applied to oxide or soluble chalcocite dump, waste, or in situ ores. A notable exception was the Lakeshore or Casa Grande operation, which utilized a roast-leach process that was successful in processing concentrates from sulfide ore. Only when sulfide ore mining at the Lakeshore Mine became uneconomical did this operation close in 1984. However, the roast-leach process was renewed in 1988 after the plant was acquired by Cyprus Minerals, who planned to import sulfide concentrates from its own mines for use in the roasting, vat-leaching process. In situ leaching was started in 1984 at the Lakeshore Mine.

By 1977, the SX-EW process had been improved to the extent that most production resulted in a very high-quality cathode that could be used directly by wire rod plants, requiring no further refining. In addition to the mine-derived, domestic electrowinning production, a plant operated by Amax Nickel Inc. in Braithewaite, LA, also produced electrowon copper from a process that utilized imported copper matte from Botswana until 1985. This production, however, does not appear in the U.S. electrowon production statistics of table 2.

Smelting-Refining.—Most copper concentrates are processed through three-stage smelting to produce anode suitable for electrolytic refining. Concentrate first is processed in the primary smelting reactor to produce a copper sulfide-iron sulfide matte containing up to 60% copper. The matte is passed to a converter where it is oxidized. Sulfur is removed from the matte as sulfur dioxide in the gas stream, and iron is removed in the converter slag. Blister copper from the converter is fire refined in an anode furnace to remove oxygen and other impurities. The anode shapes are interspersed with either

copper, stainless steel, or titanium cathode starter sheets in an electrolytic cell or tank, and copper is plated from the anode to the cathode. Valuable impurities, including the precious-metal values, collect as sludge in the bottom of the electrolytic cell.

In the 1970's, environmental constraints and energy costs became a prime concern for the domestic smelting industry. Through the late 1970's and mid-1980's, smelters used interim methods such as tall stacks and intermittent operation to meet sulfur dioxide emissions standards. However, by 1987, most remaining smelters had abandoned traditional batch reverberatory smelting and had adopted one of the various continuous, flash and oxygen-enriched methods (Outokumpu flash, Noranda, Inco flash, Mitsubishi continuous). These furnaces require lower energy input and provide a more concentrated sulfur dioxide gas stream, which allows for sulfuric acid production for sulfur dioxide capture. In some instances, the byproduct sulfuric acid not only became an inexpensive source of acid, but also contributed to the expansion of the SX-EW capacity. However, its economic value to a smelter has varied.

Flash smelting involves the blowing of concentrate, flux, and oxygen into a hot furnace. The concentrate reacts rapidly with oxygen, releasing a tremendous amount of heat. As a result, flash processes are generally autogenous, requiring no external fuel input after firing-up. In 1988, Magma Copper commissioned the world's largest single furnace Outokumpu flash smelter with a 272,000-ton-per-year blister capacity. The majority of new smelters constructed worldwide since 1970 have been Outokumpu flash smelters. However, in the United States, two new Inco furnaces, Hayden and Hurley, have been commissioned since 1980. The Noranda process smelter, installed by Kennecott, was not autogenous, but had the advantage of processing larger size material, including scrap, and producing a higher grade copper matte.

Many copper smelters have found that the limit on environmental improvement at an acceptable cost rested with upgrading the converter process. Most plants have operated Pierce-Smith converters adapted for high sulfur capture, but generally at high cost. A switch from the present batch mode of matte processing to one of continuous operation without converters is expected to be a major improvement for the future.

Canada pioneered the use of oxygen in smelting during the 1960's, and some forecast that this is the trend of the future. The use of oxygen in copper smelting was borrowed from steelmaking technology. If the smelter complex (smelting furnace, converters, and anode furnace) are considered one operation, the smelting process would use a typical ratio of total oxygen tonnage to concentrate of about 0.25 tons. A 100,000-ton-per-year smelter, treating typical southwestern U.S. concentrates, would require about 300 tons of oxygen per day. The trend is toward higher levels of oxygen enrichment in smelting; this ratio is expected to increase through the next decade to more than 0.35 tons of oxygen per ton of concentrate. In the future, most smelters are likely to process all of their primary copper sulfides by oxygen enrichment processes, whether by flash or bath smelting, by the end of the decade.¹²

The continuous top-blowing process (Contop) smelter is an autogenous process in which concentrate is continuously melted in a cyclone furnace on top of a large settling chamber. The high temperature of the flash smelting, combined with top blowing of the slag in the settling chamber, volatilizes most of the impurities such as lead, arsenic, etc., and is well suited to ores having high impurity levels. It also provides for a low-copper slag that can be dumped without further treatment. Because of its low capital requirement and compact size, it was reportedly well suited for retrofit installation at reverberatory furnaces.

Cyprus Minerals Co. was building the first Isasmelt-process smelter in the United States, which was to be operational by mid-1992. Developed by Mount Isa Mines (MIM) Co. and the

Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia, this process used a single cylindrical reactor and a submerged Siros melt smelting lance in an oxygen-enriched, high-intensity smelting process that is easily controlled and has considerably lower energy needs than Cyprus' existing Miami, AZ, electric plant. The system offered capital and operating cost advantages and resolved some environmental problems. Associated with a 500-ton-per-day oxygen plant, the process also will allow a significant increase in concentrate capacity at the Cyprus plant. Slag from the new smelter will be cleaned in the existing electric furnace, and the existing acid plant will handle all sulfur dioxide process streams. The Cyprus smelter is the only remaining electric primary copper smelter in the United States.

The foam smelting process developed in the U.S.S.R. was being used on an industrial scale at three Soviet plants; enriched air was injected into the slag melt, and smelting occurs in the resulting slag foam. This process was used only in the U.S.S.R.

Technical improvements at the refinery level have included the use of permanent stainless steel or titanium starter sheets, improved solution chemistry, and automated system control leading to greater current efficiency and reduced impurity levels. As a result of reagent and production refinements, almost all domestic SX-EW production is high-quality cathode that does not require further refining. Continuous cast rod technology, in particular, requires high-quality refined copper.

The rapid increase in continuous cast technology for rod since the middle 1970's has rendered the wirebar, an intermediate cast shape for wire rod, almost obsolete and has effectively shifted intermediary casting from the refinery to the wire mill. Though it has not replaced deep well casting of intermediate cake, slab, and billet at brass mills, continuous casting technology also has been developed for some aspects of the sheet and tube sectors.

Economic Factors

Copper is an internationally traded commodity. The copper prices established in the terminal markets of the two major metals exchanges, the Commodity Exchange Inc. (COMEX) in New York and the London Metal Exchange (LME), broadly reflect the worldwide balance of copper supply and demand. Copper prices have historically fluctuated widely annually and from month to month. Prices are affected by numerous factors, including international economic and political conditions, levels of supply and demand, the availability and cost of copper substitutes, inventory levels maintained by the exchanges, consumers and copper producers, and, to a lesser degree, inventory carrying costs (primarily interest charges) and international exchange rates. Historically, there has been a consistently inverse relationship between refined inventories held by the exchanges and the copper price, as illustrated by figure 9. (See figure 9.)

Each copper product, including scrap, from mine through refinery has a distinct pricing procedure linked, for the most part, to its copper content and the market price for copper. For example, copper concentrates, which contain between 20% and 40% copper, are purchased based on recoverable copper content and anticipated smelter and refinery charges for processing.

Copper concentrates were sold predominantly under long-term contracts, which included provisions for the delivery of specified quantities and a formula by which the price paid was to be calculated. Contracts tended to be for periods as long as 10 years, though various terms were renegotiated at shorter intervals, and thus provided smelters with secure sources of feed material. Without such contracts, new mines would find development financing difficult. Contracts provided for two types of charges. A treatment charge was made for every ton of concentrate by the smelter, and a refining charge was made for every pound of recoverable copper contained. There was generally a provision for the participants

to benefit from copper price rises. There also may be penalties for undesirable impurities, such as antimony, arsenic, and bismuth. The basis for additional payment for precious metals in the concentrates was generally slightly less than the amount contained.

Refined copper prices vary according to form and purity. Historically, the price for refined wirebar was the "bellwether" price for refined copper, because this was the dominant form traded. With the advent of continuous casting for wire rod, however, high-grade cathode became the dominant form traded. Copper wire rod prices are based on the refined copper cathode price plus a processing premium. The price spread between copper scrap and refined copper must be sufficient to allow for processing costs. Refined prices not only relate to the refined shape and its quality, but also to the manner in which it was priced, i.e., through producers' annually negotiated contracts or through the commodity exchanges of the LME, COMEX, and Mid-America Commodity Exchange (MACE). Trading in copper began on the LME, January 1, 1877, and on the COMEX, May 15, 1929. A futures exchange, such as COMEX, is a centralized market where contracts for the future delivery of the commodity are bought and sold by competitive auction. Each contract for a particular commodity is identical, representing a specific amount and grade of a commodity designated for delivery at a specified date, which may be as far as 2 years in the future. Because all futures contracts are standardized, the only negotiable aspect of a contract is price. Futures contracts changed gradually over the years to correspond to the most active markets. The LME dropped its wirebar and standard cathode contracts and, since January 1989, traded only the Grade A (high-grade) cathode contract. Similarly, COMEX converted to the High Grade cathode contract on January 1, 1990. The spot, or first position, price was most often quoted for the exchanges. To this price, however, various premiums and other charges were added to determine the actual price paid by the buyer.

Historically, the U.S. copper producers' price series was related to annually negotiated contract sales with price changes occurring at frequent intervals. When quoted, this price normally included a charge for delivery and insurance. Most U.S. producers abandoned classic producer pricing during the 1970's and 1980's, as inventories accumulated on the exchanges and the COMEX price became more influential. Producers adopted the custom of using the first position COMEX price as a basis for contract pricing. During tight markets, however, such as has existed since late 1987, the speculative influence of a COMEX-based pricing system has proved to be less than satisfactory for the consumer, owing to price volatility. The conventional producer pricing system tended to provide more stability to the market. Periods of speculative interest have usually been brief. The long period of stock surpluses since 1982 dampened speculative interest until the end of 1987. Since that time, both producers and consumers have increasingly used futures contracts and the newly introduced copper options to hedge their sales and purchases.

Speculation in copper markets has been active since 1987 and has achieved a sophisticated level as trading advisors and fund managers devise ever more complicated schemes with futures and options. Their goals have become more obscure and less obtainable with prices that can be distorted briefly with wild price fluctuations. Some believe that the quiet, orderly markets enjoyed in the past are gone forever. Contangos can bring certainty and stability to markets, and backwardations can bring excitement and opportunity to make money. When and whether or not to intervene in a market is always a problem faced by the commodity exchanges. The U.S. authorities are quick to do this through raised margins and other mechanisms, but there always is a danger of losing speculators. Although the LME allows for price fluctuations, the planned use of "Asian" options might considerably lessen their frequency. Application of the average rate, or Asian options, is

designed to prevent too much activity happening on one day, usually the third Wednesday of the month, which is the exercise date for all maturing options. This is done by averaging the settlement dates of the first 3 weeks to provide an acceptable exercise price for the option, providing greater protection for the hedger. An added advantage is the spreading of speculative activity and dampening of inflammatory effects from sophisticated investment fund manipulation of the market. Many physical trading deals rely on averaging for pricing, and this approach reportedly is already widely used on the over-the-counter trade. On the LME it increases price transparency, lowers costs, and provides better financial and regulatory protection for users. Singapore is currently the only non-European country to have an approved LME warehouse for copper.¹³

Based on constant dollars, one must look to the depression era of the 1930's to find prices as low as those occurring between 1981 and 1988. Since that time, prices have been within the range of the constant dollar average for all prices, 1901-90. Copper prices not only responded to changes in the world economy, but also to the effects of large copper inventory accumulation, to copper cartel actions to restrict production, which were most effective prior to World War II, and from time to time to speculative influences on the commodity exchanges.

A word of explanation must be given about the relationship between the cost to produce and the market price for copper, which can be obscured by the many factors that affect both. It is certain, however, that the cost to produce has less influence on the market price for copper than does the marketplace, as set by the balance between supply and demand. Copper prices often have sunk below the average cost to produce during times of surplus, causing most world producers financial difficulty and providing considerable incentive to implement new cost-cutting technology. Contrarily, when markets are balanced, prices can be considerably above the average cost to

produce, owing to the effects of speculation. Adding confusion to the understanding of cost versus price is the fact that mines cannot be moved to an area of cheaper labor or energy when these are required as a result of international monetary manipulations. Devaluing a currency can cause temporary lower domestic costs at the mine, thus changing a nation's competitive stance. Contrarily, overvaluation of a currency can cause local costs such as labor and energy to be excessive and possibly even cause temporary closure of a mine if occurring during a period of world surplus. The latter situation was the case for U.S. producers during the early 1980's. Because of the strong dollar, the relative cost to produce for U.S. producers was higher in dollar terms than those of the rest of the world. In dollar terms, the world's producers outside of the United States were being paid extremely high for an equivalent pound of copper, while their domestic costs were covered by a devalued currency. When excess stocks were depleted and market balance finally was achieved in 1987, the "high-cost" U.S. mines were again operating and increasing production as world leaders in cost-cutting technology. Mines could not be moved or relocated to other countries in response to market demand and changing cost structures. There was no lower cost mine capacity elsewhere in the world to replace the significant U.S. copper contribution to world supply.

Refined copper inventories are kept on hand by consumers and producers as a means to meet demand. A just-in-time inventory philosophy in recent years has been assisted by the advent of the computer, allowing a more accurate analysis and timing of production and shipments. Normally, about 4 weeks of supply is considered adequate to meet market needs and prevent excessive speculation. Whenever inventories exceed this mark, prices tend to be lackluster, and conversely, whenever inventories are below this mark, speculation can drive up market prices. Surplus inventories may find their way to the commodity exchanges where their high visibility can

depress prices. The exchanges also provide a mechanism for hedging production and consumption, providing liquidity to the market. The primary economic purpose of futures trading is to provide a marketplace for hedging against the financial risk associated with volatile fluctuations in prices by transferring that risk to speculators.

Surplus refined copper inventories not only have accumulated periodically in response to periods of economic recession, but also as a result of U.S. Government purchases for the National Defense Stockpile. There is an inverse relationship between the amount of commercial stocks on hand and the market price for copper. High inventories levels have had a depressing effect on prices when these surplus supplies were released onto the market to compete with newly mined copper. Trends in U.S. copper inventories since 1955 are shown in table 3. (See table 3.)

The U.S. Government has been historically a large holder of refined copper inventories, but since the final large release of 1974 has not attempted to refill the National Defense Stockpile, which was released for the most part in response to the shortages of the Vietnam War years. From time to time, other nations such as Japan also have held refined copper stocks for strategic reasons. Materials shortages created during World War II prompted the creation of the National Defense Stockpile late in the 1940's. Beginning in the 1950's, the National Defense Stockpile became a vehicle for controlling the flow of mineral supplies during an emergency, buying copper in times of surplus (524,000 tons was purchased between 1953 and 1958; very little has been purchased since) and selling copper in times of shortage (808,000 tons was sold between 1965 and 1969 and 229,000 tons in 1974). The stockpile currently holds 26,352 tons of copper materials, including 20,000 tons of refined copper, 6,124 tons of copper in brass scrap, and 548 tons of nonstockpile-grade copper.

Operating Factors

Production Costs.—In recent years all domestic and most world producers endeavored to cut production costs in an effort to remain competitive through prolonged periods of depressed prices, such as that experienced during the mid-1980's. Domestic producers adjusted mine plans, reduced stripping ratios, and raised cutoff grades. Large capital investments were made in new in-pit crushing and conveying systems and on mill and concentrator expansions or replacements. Lower cost SX-EW capacity was expanded to process both oxidized ores and the higher grade waste dumps resulting from higher cutoff grades. Consolidation of assets through ownership changes improved operating efficiencies. Labor costs were reduced through improved employee productivity and wage and work-rule concessions by union and nonunion miners. Productivity at mines, in terms of hours of work per ton of copper produced, declined from more than 40 hours in 1980 to 28 hours in 1983 to an average 18.2 hours over the 1985-91 period. Similar cost savings were realized through smelter renovations and renegotiation of smelter contracts.

Byproduct values and the combined effects of inflation, government monetary policy, and exchange rates also affected operating costs. In the United States, technological improvements overcame the competitive disadvantage caused by shifting byproduct credits and the effects of inflation and exchange rate (I/ER). Conversely, devaluation of the kwacha and improved byproduct prices allowed Zambia to remain competitive despite deteriorating technical factors.¹⁴

Capital Costs.—An analysis of 71 planned and constructed new mine projects for which total development costs had been estimated for construction over the years 1991-2000, in Argentina, Australia, Brazil, Botswana, Burma, Canada, Chile, the Commonwealth of Independent States (C.I.S.), Indonesia, Malaysia, Pakistan, Panama, Papua New Guinea, Peru, Philippines, Turkey, and

the United States, indicated that an average of \$7,400 per ton of annual copper capacity, or about 8 cents per pound of recoverable copper must be invested to bring a new mine on-stream. Mine expansions at established mines, on the other hand, averaged \$2,500 per ton of copper capacity. A new SX-EW plant in the United States would cost an average of \$1,500 per ton. Kennecott's new smelting and refining complex was estimated to cost about \$3,000 per ton of capacity. New mine costs varied widely with location, size, and type of mine. For example, the 300,000-ton-per-year Escondida open pit mine in Chile was estimated to cost about \$2,600 per ton of copper, or only 3 cents per pound of recoverable copper over the life of the mine. In contrast, the Windy Craggy Mine in British Columbia might cost \$8,000 per ton of installed capacity and 5 cents per pound of recoverable copper and the Tambo Grande Mine in Peru about \$15,000 per ton of installed capacity and 11 cents per pound of recoverable copper, according to currently published estimates.

Total project financing also varied with location, size, and type of mine. Financing required for expansion at an existing mine ranged between \$66 million for the Olympic Dam, Australia, expansion to \$500 million for the Chuquicamata, Chile, expansion. The average new mine would cost \$242 million to develop. Of eight new open pit projects in Chile, the average cost was \$381 million for an average capacity of 122,000 tons of copper per year; in Peru, the average cost for two open pit projects, currently in exploration stages, was \$216 million for an average capacity of 35,000 tons of copper per year; and, in the United States, the average cost to construct a new open pit mine with an average capacity of 44,000 tons per year was estimated to be \$137 million. Some individual projects, such as the La Escondida Mine, cost as much as \$800 million to bring into production. The average of five SX-EW projects was \$207 million in Chile, or \$3,700 per capacity-ton. The average for four SX-EW

projects in the United States was \$15.7 million and \$1,800 per capacity-ton.

Environmental Requirements.—The many environmental protection laws and regulations that have been promulgated in the United States since the late 1960's have affected the copper industry in many ways. Most of the cost of compliance with environmental regulation was incurred at the smelter level. Although some regulations have resulted in offsetting costs through production of an additional salable product, such as sulfuric acid, and reduced operating costs in modernized smelters, the net effect has been to increase total operating costs.

Laws and regulations in force that affect U.S. copper operations include those promulgated under the Federal Clean Water Act; the Clean Air Act of 1970; the National Environmental Policy Act of 1969; the Solid Waste Disposal Act (including the Resource Conservation and Recovery Act (RCRA) of 1976); the Federal Surface Mining Control and Reclamation Act; the Toxic Substances Control Act; the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA); and numerous State laws concerned with mining techniques, reclamation of mined lands, air and water pollution, and solid waste disposal. Transportation of mineral and hazardous substances also was regulated. Ground water regulations in Arizona were being developed and could have a greater impact on the copper industry than surface water quality. In 1990, the Arizona Aquifer Protection Permit (AAPP) program became an important factor. Arizona's Groundwater Protection Permit Program was expanded and refined into the AAPP. To obtain a permit, mining facilities must meet two tests: the Best Available Demonstrated Control Technology (BADCT) must be installed and the facility must show how it will protect ground water standards, above and beyond installation of BADCT.³⁰

Under the 1980 Bevill Amendment to RCRA, solid wastes from the extraction, beneficiation, and processing of ores and minerals were temporarily exempted from

regulation as hazardous wastes under subtitle C, pending a comprehensive study to determine potential hazard and feasibility of treatment. EPA published an interim interpretation that placed wastes from exploration, mining, milling, smelting, and refining within the exclusion pending completion of a Report to Congress. Acting under a court-ordered deadline, in 1986 EPA issued its regulatory determination in which it concluded that subtitle C regulation was not warranted for mining and beneficiation wastes. However, EPA proposed to narrow the scope of the Bevill exclusion, by implicitly applying a high volume, low hazard standard to these special wastes that would generally remove most mining and smelting wastes from the exclusion. This concept had been introduced by regulations proposed in 1978 for a universe of special wastes that were less amenable to RCRA control techniques. EPA subsequently withdrew its proposal to reinterpret the exclusion boundary.

The withdrawal of EPA's proposal to reinterpret was challenged in court, and in October 1988, the court found that the intent of the Bevill exclusion was to include only those wastes from processing ores that met a special waste criteria of high volume and low hazard. In compliance with the court, on October 20, 1988 (see 53 FR 41288), EPA published a proposal to define the scope of the exclusion and listed 15 wastes that met the necessary criteria. On April 17, 1989 (see 54 FR 15316), the agency published a revised list containing 6 wastes that it believed met all the necessary criteria and an additional 33 wastes that they conditionally proposed to retain until further study. EPA felt that these 33 wastes met the high volume criteria, but there were insufficient data to determine if they met a low hazard criterion, established, for the first time, in the April proposal.

On September 1, 1989 (see 54 FR 36592), EPA published a Final Rule for Bevill exclusion criteria and proposed a final list of 5 wastes to be temporarily retained within Bevill, including slag from primary copper processing, as well

as a reduced list of only 20 mineral processing wastes for conditional retention. Four wastes, including acid plant and scrubber blowdown from primary copper processing, were permanently removed from the Bevill exclusion. Two other copper associated wastes, bleed electrolyte from primary copper refining and wastewater from primary selenium production, were omitted for further consideration of exclusion. This final rule contained a modified definition of "processing of ores and minerals" that incorporated leaching operations and roast leaching operations, and a modified definition of "large volume." On September 25 (see FR 39298), EPA narrowed the list of conditionally retained wastes to only 13.

On January 23, 1990, EPA issued a final rule that retained 15 wastes, in addition to the 5 retained in the September 1 notice, within the exclusion pending preparation of a final Report to Congress and subsequent Regulatory Determination. The copper processing wastes retained were calcium sulfate wastewater treatment plant sludge from primary copper processing, copper slag, and slag tailings from primary copper processing.¹⁵

The major thrust of the Clean Water Act (an amalgam of numerous acts and amendments, including the Federal Water Pollution Control Act of 1972 and Clean Water Act of 1977 and some 23 amendments) and its legal interpretation is through its elimination of pollutant discharge into navigable waterways through the National Pollutant Discharge Elimination System (NPDES), which provides for a permitting system to clean up discharge of process wastewater, mine drainage water, stormwater runoff, and nonpoint sources. In U.S. copper mills, processing plants, and semifabricating plants, most process water is reclaimed and reused, particularly in the Southwest where there is a chronic water deficit. Mine water discharge problems usually occur when a mine and mill shut down, largely because there is no place, such as a mill, to use the continuously discharging mine water.¹⁶

Energy Requirements.—Open pit mining may extend to as much as 1,500 feet below the rim, and the energy required for hauling rock from such depths becomes an important cost factor. Hauling by truck was estimated to consume as much as 54% of the total energy consumed by all processes in the pit, including drilling, blasting, loading, hauling, and ancillary processes. Grinding and concentration consume about 45% of the energy used in the milling. The lower the ore grade, the more ore that must be processed, the finer the grinding required and thus, more energy consumed.

Major improvements in energy use in mining and milling have been made in recent years through improved strategies in grinding, concentration, and ore transportation. The use of large flotation cells has improved process efficiency and has lessened energy usage. Hydrometallurgical processes for copper recovery, such as the SX-EW recovery of copper, require more energy than pyrometallurgical processes. Electrowinning consumes 21 to 24 million British thermal units (Btu) per ton of cathode, or almost 20% of the total required from mine through refining stages. The in situ extraction of copper is the least energy consuming process, despite the low (50%) recovery. Energy consumption in dump leaching was higher because it is required for leachate circulation and cementation. The combined total energy required for dump leaching, cementation, and refining is about 94 million Btu per ton of cathode copper.¹⁷

Flash furnace technology and the Noranda and Mitsubishi continuous smelting technologies have resulted in energy savings. Energy consumption in millions of Btu per ton of refined copper recovered was reported¹⁸ as follows: Outokumpu flash smelting (18.92 million Btu), Inco flash smelting (21.25 million Btu), Noranda continuous smelting (24 million Btu), Mitsubishi continuous smelting (19.16 million Btu), and Oxy Fuel Reverberatory smelting (26.62 million Btu).

Transportation.—Seaborne cost for shipping copper concentrates from the United States to Japan or Europe ranged between \$22 to \$30 per metric ton of concentrates.

ANNUAL REVIEW

Legislation and Government Programs

Copper Study Group.—Preparations were initiated during 1991 for the final meeting to determine the existence of the International Copper Study Group (ICSG). First proposed in 1985 by the United States, at the request of several domestic companies, the ICSG was to be formally established on January 23, 1992, in a meeting held in Geneva, Switzerland. Countries representing 59.25% of the world trade in copper voted to accept the Terms of Reference (TOR), including the imminent acceptance by Zambia. Japan also intended to join as soon as certain technical amendments to the TOR can be made. By the January meeting, the following Governments had deposited their acceptance of the terms of reference with the United Nations: Belgium-Luxembourg, Chile, China, Finland, France, Germany, Greece, Italy, Netherlands, Norway, Peru, Philippines, Poland, Portugal, Spain, the United States, and the European Community (EC). Canada was to join just prior to the inaugural meeting, which was to be held in Geneva on June 22 to 26.

The ICSG made its appearance as an answer to some past and some current concerns about the world copper industry. Some of the concerns mentioned are a slow or erratic increase in copper demand and uncertainties associated with unstable prices and the future course of copper markets. Problems arising from these issues lead Governments to intervene in the market, and further, to adopt policies that may be harmful to the interests of other countries or to the copper industry as a whole. This group is to provide a forum for all market participants, both producers and consumers, to examine their common problems and to provide for an open dialogue and free exchange

of information. Greater transparency of the market is an important goal of this group through more complete, reliable, and up-to-date statistics, as well as through special investigations. Greater market transparency should reduce the chance of companies making incorrect market strategies, or of government error, when conceiving and applying basic production and trade policies.

The ICSG mandate stated the group's objective as intensifying international cooperation on issues related to copper, improving available information on the international copper economy, and serving as an adequate setting in which governmental consultations on copper may be discussed. The ICSG was to have the following functions: (1) to organize proposals and information exchanges on the international copper economy; (2) to improve copper statistics; (3) to evaluate periodically the market conditions and the prospects of the copper industry; (4) to perform investigations on issues of interest to the Group; (5) to hold discussions on ways and means of increasing copper demand and suggest market development projects that would be directed to, and undertaken by, established market development organizations; and (6) to research the problems and special difficulties that exist or could arise in the international copper economy.

Environmental Actions.—The EPA issued its final regulatory determination required by section 3001(b)(3)(C) of RCRA for 20 special wastes from the processing of ores and minerals. EPA planned to address 18 of the wastes under subtitle D, possibly in the program being developed for mining wastes. The 20 wastes covered included slag, slag tailings, and calcium sulfate wastewater treatment plant sludge from primary copper processing. Copper slag from primary copper processing was included among the four wastes that did not exhibit a hazardous characteristic, but for some of which, adverse environmental impact cases that affected surface water had been documented. EPA found that copper slag rarely, if ever, exhibited a hazardous

waste characteristic. Only 1 sample out of 70 exceeded EPA-toxicity regulatory levels for cadmium and lead. An examination of the slag management practices and environmental conditions for 10 active primary facilities indicated that slag currently generated posed a low risk to human health and the environment. As a result, regulation under subtitle C was not deemed appropriate. On the other hand, the Agency recommended subtitle C regulation for calcium sulfate wastewater treatment plant sludge, focusing only on the remaining active generator, located in Garfield, UT. The sludge at the Garfield facility was EP-toxic for arsenic. Even so, EPA found that current practices at the Garfield facility were adequate to limit contaminant releases and associated risks.¹⁹

EPA also issued a correction to the final rule on drinking water regulations for lead and copper on July 15. The national primary drinking water regulation for lead and copper was issued on June 7, but a provision for sampling techniques for measuring these metals was omitted and appeared in the correction. The maximum contaminant level for lead set by this rule was to remain effective until December 7, 1992. Each first draw tap sample for lead and copper testing was to be 1 liter in volume and was to have stood motionless in the plumbing system of each sampling site for at least 6 hours.²⁰

Trade Actions.—The United States stepped up its fight in the multilateral trade negotiations under GATT over the Japanese copper tariff in an effort to have Japan lessen or abolish its almost 5% tariff on refined copper imports. U.S. imports of refined copper to Japan have increased significantly in recent years. The EC also joined the United States during the Uruguay round, and although Japan's Ministry of International Trade and Industry (MITI) had resisted efforts to abolish the duty, it indicated a willingness to reduce it. The EC and the United States would like refined copper to be included in a list of zero options or materials on which duties have been

completely eliminated between the countries concerned. Japan imposed an import duty of 15 yen/kilo (\$0.052 per pound), or 5% ad valorem, for refined copper cathode. MITI offered a 33% reduction in its ceiling rate to \$0.049 per pound.

Congress took action to extend China's most-favored-nation (MFN) status until July 1992, but the country would be required to meet stringent standards set to improve its record on both human rights and arms sales.

Issues

Industry Investments, Earnings, and Ownership Changes.—The impact of copper on Arizona's economy in 1991 was \$5.65 billion, according to a report prepared by the Western Economic Analysis Center in Marana, AZ. Direct contributions to the economy were more than \$1.51 billion, which was down slightly from \$1.54 billion in 1990. Several categories, including numbers employed, earnings, and property tax payments, were reported as increasing. Arizona's mines annually produce more than 60% of the Nation's copper. Industry payments to State and local governments were almost \$101 million last year, down about 5% from that of 1990. By comparison, property taxes paid, at \$41.4 million, were almost 23% higher than the \$33.7 million paid in 1990. Lower copper prices caused the State income taxes to be lower.

ASARCO Incorporated's net earnings for the year were \$46 million, compared with \$149.1 million in 1990. Lower prices for metals were the major factors in the lower earnings. Earnings were also reduced by a deduction of \$6.6 million that was used to establish a reserve for a copper customer that had filed for bankruptcy. The company discontinued equity accounting for its investment in Mexico Desarrollo Industrial Minero, S.A. de C.V. (MEDIMSA), after considering the sale of this investment. The company spent \$282.9 million for property additions in 1991, including \$207.5 million for the copper expansion and modernization

program at the Mission and Ray copper mines and the El Paso copper smelter and \$12.3 million for payments on previously acquired properties. The company set aside a \$75.5 million charge to earnings for closed plant and environmental liability reserves. At yearend, these environmental reserves totaled \$104.2 million. Cash expenditures from these reserves were \$32 million in 1991, \$13 million in 1990, and \$13 million in 1989.²¹

Cyprus Minerals Co. reported income from its copper segment as \$132 million for 1991, down from \$166 million reported in 1990. Total revenues from copper and molybdenum operations was \$905.7 million. Lower copper prices and higher production costs were blamed for the fall in earnings in 1991. Profits were reduced by after-tax asset write-downs and accruals of \$31.8 million, primarily in talc and coal. The worldwide economic slowdown also had an adverse impact, primarily due to copper prices, down one-third from a 1988 high, depressed molybdenum prices, and declines in coal prices.²²

Despite improvements in Magma Copper Co.'s operating performance, total sales decreased to \$724.8 million in 1991 from \$754.2 million in 1990, primarily as a result of copper price decline. In addition, the company recorded a net loss for 1991 of \$120.5 million, compared with a net income of \$82.7 million for 1990. The net loss was attributable to various accounting adjustments that had no effect on its cash-flow. The noncash accounting adjustments reflected studies concerned with reorganization of the company into profit centers, a new collective bargaining agreement, and feasibility studies for the lower Kalamazoo ore body. An after tax restructuring charge was taken of about \$141 million, which included a \$92 million after tax write-down of the company's investment in its Kalamazoo ore body. Magma's copper operations also produce gold and other byproducts. Revenue from gold sales in 1991, including gold purchased from others, was \$18.2 million for 48,338 ounces. Silver revenue was \$11.3 million on sales

of 2.9 million ounces. Molybdenum disulfide sales were \$10.8 million for 5.4 million pounds.²³

In 1991, Phelps Dodge Mining Co. had earnings from operations of \$367.5 million on revenues of \$1.3 billion and invested \$262.6 million in capital programs. Phelps Dodge had invested more than \$110 million to keep the Hidalgo smelter in Playas, NM, at the leading edge in technology. Construction continued on the \$112 million Northwest Extension project at Morenci, AZ, which when completed in 1992 will add 70,000 tons per year of SX-EW cathode. Two other substantial capital programs continued: reentry into the Metcalf pit and extension of the ore crushing and conveying systems. Both projects will allow the Morenci operation to maintain low-cost production. Phelps Dodge owned a 16.25% interest in Southern Peru Copper Corp. (SPCC), which operated copper facilities in Peru and received an after-tax dividend payment of \$8.8 million from these operations in 1991. Lower company earnings in 1991 were the result of lower copper prices, higher production costs at Tyrone, and increased mining costs associated with moving into the Metcalf area of the Morenci Mine.²⁴

Colonial Metals Co., of Columbia, PA, bought out the 60-year-old former Bay State Refining Co. Inc. in February. Renamed Chicopee Alloys Inc., the brass and bronze ingotmaker, was looking into newer markets.

Mine and Plant Labor.—Productivity at all mines from which copper was produced as a principal product was 17.7 worker-hours per ton of recoverable copper produced by open pit, underground, and leach methods, a considerable improvement compared with 46.1 worker-hours per ton in 1973. Average productivity, including mine and mill operations, was 26 worker-hours per ton for 3,657 workers at 12 underground operating mines and 17 worker-hours per ton of recoverable copper for 10,028 workers at 17 open pit mines. The number of workers at U.S. copper mines and mills averaged 13,706 in 1991.

Arizona led in average number of mine and mill workers (9,524), followed by New Mexico (1,549 workers), Utah (1,211 workers), and Michigan (918 workers), according to Mine, Safety, and Health and Administration (MSHA) reports. (See table 4.)

In 1991, the average number of copper workers was up by 9.3% in Arizona, and copper workers continued to lead other Arizona industry workers in average weekly earnings. A copper miner's average weekly salary in 1991 was \$684. That was above the second highest, manufacturing, which was \$586. Industrywide employee earnings totaled \$430 million, up 4.9% from \$410 million paid in 1990.²⁴

Cyprus Minerals' copper operations in Arizona employed about 3,000 people. Its Arizona facilities included a mine and mill at Bagdad, a smelter and mine at Globe-Miami, and mines and mills near Tucson and in Pinal and Mojave Counties.

Magma Copper negotiated a 15-year collective bargaining agreement in October 1991, more than 8 months prior to the expiration of their existing contract. The agreement prohibits strikes and lockouts for at least 7 years. Hourly rated employees will receive annual wage increases of \$0.25 to \$0.35 per hour in each of the next 5 years, some of which are dependent on Magma's quarterly earning performance during such period. After the initial 5-year period, the agreement will continue in effect for an additional 10 years on the same terms, unless a modification is proposed by either party. If they are unable to agree on modifications, an arbitration panel will establish economic terms for 1 year. If during any 5-year period after the initial term there are two such arbitrations, the agreement will terminate upon the date of the arbitration award. At the end of 1991, Magma had 4,487 employees, of whom 3,176 were hourly wage employees. The United Steelworkers of America (USWA) represented the largest number of employees. At Pinto Valley, four individual unions were jointly certified; of these, USWA was the largest.

Phelps Dodge employed almost 2,000 people at the Morenci Mine in Arizona. Almost 1,150 people were employed at the company's Chino, NM, operations in 1991, according to the Phelps Dodge Annual Report.

Production Costs.—Most U.S. companies reported increases in costs for 1991, owing to higher labor, energy, and processing costs. Higher costs and lower metal prices affected most company earnings. Even so, cost containment continued to be a major focus of most companies with many continuing to implement cost saving changes.

Operating problems at Asarco's Ray mine and smelter complex adversely affected the company's earnings in 1991, according to the annual report. Selling and administrative costs increased to \$107.9 million in 1991 from \$95.5 million in 1990, principally to resolve a bad debt reserve for a copper customer. Depreciation and depletion costs were about the same as those in 1990, as increases arising from the capital spending program were offset by changes in production and ore reserves. Research and exploration costs were also unchanged from those of 1990.

Copper Range was implementing major cost-cutting changes to improve productivity. These included changes in communications, blasting patterns, jumbo machinery, mobility, and improved maintenance procedures. In an effort to improve communications, a consultant firm, Universal Schedule Corp. (USC), was employed. USC analyzed delays and advised of the consequences. USC also sought to improve communications between shifts, as well as between miners. New techniques for more efficient operation of new machinery were also introduced. The result was a 15% to 20% increase in productivity. Copper Range was reactivating the fourth grinding circuit, which had been purchased back from Echo Bay Ltd. The fourth circuit was about 90% complete at yearend. The company was also experimenting with column flotation. Four Diester columns were in operation, replacing a bank of 50 older flotation

cells. Mill capacity was about 30% greater than mine capacity with all four sections in working order.

Cyprus Minerals reported that it did not achieve anticipated reductions in copper costs in 1991. According to the company annual report, Cyprus Minerals sold 291,206 tons of copper in 1991, up from 276,691 tons in 1990, but its production costs climbed to 80 cents per pound, while the price received was 14 cents per pound lower than that in 1990. The company had been trying to streamline costs and unload underperforming assets. Cyprus Minerals made a decision to move its copper operations from Englewood, CO, to Phoenix, AZ, as part of an austerity program to trim its headquarters staff 43% and refocus on its core copper and coal production.

Factors affecting improvements at Cyprus Minerals included operations hampered by heavy rains in the first quarter, lower ore grades at several mine locations, and reduced revenues from molybdenum byproducts. The worldwide shortage in smelting capacity caused toll conversion costs to increase from less than 20 cents per pound to more than 25 cents per pound during 1991. As a result of this cost increase, Cyprus Minerals decided to toll smelt only small quantities of concentrates, while most would be processed through its Lakeshore roast/leach facility and/or stockpiled. Sales of copper were expected to drop to 249,476 tons in 1992. The biggest impact in cost improvement was expected to result from the Miami, AZ, smelter expansion and modernization. Productivity was expected to increase through the addition of 240-ton haul trucks at all Cyprus Minerals' Arizona copper mines. Costs were cut at the Miami Mine through an innovative gauge that made it possible to fill a mine truck fuel tank only once per day, reducing spills and saving \$200,000 per year.²⁶ Employees at Cyprus Minerals' Sierrita and Twin Buttes Mines in Arizona developed a mobile filtration/recycle system to reclaim oil during repair procedures, allowing the oil to be screened, cleansed, and returned to the

vehicle on-site, creating both cost savings and environmental benefits.

Magma Copper's net cash costs for copper sold have decreased from \$0.78 per pound in 1988 to \$0.71 per pound in 1991. Net cash costs per pound represent (1) costs of Magma source copper sold (excluding depreciation, depletion, and amortization) reduced by credits for byproducts and profits from custom processing divided by (2) total pounds sold from Magma sources.²⁷ The company attributed its reduced operating costs primarily to productivity increases, improved labor relations, full operation of its retrofitted smelter, and to a lesser extent, the increased use of the lower cost SX-EW method.

Production costs at Phelps Dodge's operations in 1991 were higher than in 1990, principally because of increased mining rates, lower ore grades, and higher costs for certain operating supplies, according to the Annual Report. However, the costs generally continued to reflect the high levels of production, the cost containment programs that were put into place, and increased copper production from SX-EW. SX-EW recovery of copper from low-grade ore stockpiles was a low-cost process. Substantial capital programs, completed in 1991 or now under way, were expected to contain further escalation of production costs. During the past 3 years, inflation impacted production costs, especially on energy and supply costs.

Production

Mine Production and Reserves.—Copper was mined in 13 States during 1992, with Arizona maintaining its lead with 63% of the total, followed by New Mexico and Utah. There were 65 copper-producing mines, up from 62 mines in 1990. Of these, 33 were copper mines and 32 were mines from which copper was produced as a byproduct or coproduct of gold, lead, silver, or zinc. Total U.S. operating mine capacity, in terms of recoverable copper, was estimated to be 1.96 million tons in 1991 compared with 1.86 million

tons in 1990. The growth was mostly the result of further increases from SX-EW production. Reserves at the major producing companies were reevaluated with some significant increases, as shown in table 5. (See table 5.) The number of unpatented mining claims held on Federal land fell about 13% during 1991 in Arizona, as exploration was cut back.

Arizona Metals Co. (Arimetco) completed a 27.2-ton-per-day SX-EW plant at Yerington for slightly more than \$5 million, including the cost of leach-pad construction. The company finalized an agreement with Billiton Metals to buy all of Arimetco's copper production for 5 years. The agreement included financing that allowed Arimetco to expand SX-EW capacity to more than double that of the existing facilities, raising Yerington's total capacity to 36.3 tons per day of cathode copper. About \$3 million was to be spent to renovate the original Yerington plant to produce 13.6 tons per day of cathode. Arimetco intended to develop the Yerington project in three stages: the first stage, already completed, included the installation of a crusher-conveyor system and leach treatment system with an 11.3-ton-per-day SX-EW plant. That system was completed in late 1989. The second stage included SX-EW plant expansion and another leach pad area. The low-grade Yerington ore is leached in two stages, each for 30 days. A feasibility study was ongoing for the third stage, which calls for open pit mining of the sulfide reserves, milling and concentration, roasting, leaching, and SX-EW processing.

Arimetco purchased the Ann Mason copper deposit, originally owned and explored by Anaconda Co. in the mid-1970's. Less than 3 miles from the Yerington pit, the Ann Mason contains indicated ore of 999 million tons of ore grading 0.51% copper. With this ore is a higher grade core of 7 million tons grading more than 1.0% copper that lies beneath several hundred feet of overburden. Lower grade, but economic ore may be accessible by stripping 150 feet of overburden. The Ann Mason deposit may be used to replace Yerington

pit ore on its depletion. Estimated project life would be about 30 years.

The 5,700-ton-per-year SX-EW plant at Arimetco's Johnson Mine cost \$3.3 million to build. The plant was constructed in about 4 months so that production began in late 1990. Arimetco planned to operate on stockpiled ore while preparation of the new pit outline was undertaken. The Johnson pit contained an estimated 3.6 million tons of ore grading 0.7% copper. Much of the ore lay beneath an existing truck haulage ramp used in earlier mining by Cyprus Mines Corp. When the pit is completed, the mining rate will increase gradually to 13.6 tons per day. In addition to the pit area being mined, the Johnson Mine had potential reserves of 21.9 million tons grading 0.27% copper that could be used to produce about 4,800 tons of copper per year. These reserves were located in 13.6 million tons near the mine and 9.6 million tons of reserves in the Copper Chief deposit.

Arimetco sold the Emerald Isle property to Holcorp Gold Mines for \$3.75 million. Arimetco was to build a 3.6-ton-per-day SX-EW plant for Holcorp. The sale was to be finalized in early 1992.

Arimetco purchased a 50% interest in the MacArthur deposit, 4 miles from the Yerington facilities. Holcorp Mines owned the remaining 50% interest in MacArthur and intended to finance construction of the two leach pads that will be used for MacArthur ore. The MacArthur deposit contained proven reserves of 36.3 million tons of 0.22% ore, including an open pit area with 8.3 million tons of 0.43% copper. Arimetco and Holcorp purchased the property from Timberline Minerals of Reno, NV, for \$3.8 million. The MacArthur plant will be placed adjacent to the new SX-EW plant that Arimetco recently completed at Yerington.

Arimetco acquired the Van Dyke property lease in 1990, and in 1991, completed a private placement of \$8.75 million to finance development. The reserves, under the town of Miami, AZ, are 226,800 tons of leachable copper. Arimetco was conducting feasibility

studies of the Van Dyke property, which contains a large amount of deep copper reserves exploitable by in situ leaching. Both Occidental Minerals Co. and Kocide Mining Co. explored and drilled this property before suspending operations due to various technical reasons. Arimetco acquired Van Dyke in 1990. Initial operations at Van Dyke were to focus on a 9.1-million-ton block of ore in and around the old workings and grading about 0.50% copper. Later, hydrofracturing and star-pattern injection and collection methods were to be used to extract copper from south of the old workings. A 13.6-ton-per-day SX-EW plant was to be constructed by Arimetco, although initial production was to be lower in the early stages.

Asarco launched a 3-year, \$260 million campaign to modernize and expand copper production facilities in 1989. Included were a \$130 million equipment upgrade at Ray Mine and a \$30 million program at its El Paso, TX, smelter. Expansion of mining at the Mission complex and renovation of the idle Pima concentrator were budgeted at \$94 million. Asarco acquired the Pima mill from Cyprus Minerals Co. for \$12.5 million. The Pima property included two mills and contained almost 35.4 million tons of copper ore grading 0.61% copper. The No. 1 mill was originally built by Fluor Utah in December 1971. The No. 2 mill was the one renovated. Cyprus Minerals Pima Mine stopped production in 1977 and remained inactive until April 1979. The No. 2 mill operated until October 1982, when it was shut. The property has been renamed Mission South. Asarco's mill renovation started in July 1990 and was completed by October 1991. Major modifications included addition of a SAG recycle crushing circuit. Flotation circuits were replaced with 1,500-cubic-foot cells. The main control room was also remodeled and reequipped with state-of-the-art process control systems.

Asarco was waiting for permits to allow production from a new SX-EW plant at the Silver Bell Mine. The new plant would produce 16,330 tons per year of copper cathode. Silver Bell was

producing precipitates from dumps remaining from ore mined in 1984. Precipitate production would cease by yearend 1993.

Azco Mining continued development on the Sanchez deposit in Graham Co. Reserves were 152 million tons grading 0.34% copper. Initial public hearings and a draft environmental impact statement were completed. Funding was being sought.

Cambior USA acquired control of the Carlota and Cactus deposits in Gila County, AZ, by purchasing Westmont Mining from Costain Minerals. Drilling indicated resources of 49 million tons, containing 0.45% copper. A prefeasibility study indicated an open pit, SX-EW operation producing 17,320 tons per year over an 11-year mine life.

Budge Mining had been drilling at the Korn Kob copper skarn deposit, Pima County, AZ, since 1989. After proving reserves of about 16.3 million tons of 0.40% copper, the property was released to the owner, Keystone Minerals.

Copper Range Co., a Metall Mining Corp. subsidiary, invested an additional \$7 million in new equipment, supplementing the \$9 million invested in 1990 at its White Pine Mine, MI. Ore milled at the White Pine Mine for 1991 was about 52.6 million tons and the refinery produced 52,617 tons of cathode in 1991, according to the company annual report. The underground operation consisted of two different producing sections, the northeast (NE) and southwest (SW) sections, which are interconnected. The NE had lower grade than the SW, but its geology was more uniform, predictable, and practically fault-free. The SW dipped 16% to 18% and suffered from heavy faulting. Previously, the SW was the mainstay, but during 1991, a program was started to reduce SW production so that it comprised only 45% of the effort. The mine plan called for five mining units in the SW and nine mining units in the NE next year.

Starting in 1989, Copper Range made several changes in its mining operations. Truck haulage was eliminated and ore was transported directly from the face to

Stamler feeder-breakers using load, haul, and dump (LHD) equipment. The average haul distance was also reduced by 200 feet, improving feeder-breaker move times. The feeder-breakers feed 36-inch conveyors, which dump onto larger belts.

The Pebble Beach porphyry copper-gold deposit was discovered in 1990 by Cominco Resources in Alaska. Preliminary reserves were estimated at 454 million tons grading 0.35% copper and 0.011 ounce per ton of gold. Pebble Beach is in south-central Alaska, 200 miles southwest of Anchorage and 60 miles from water.

Cyprus Minerals produced a total of 291,207 tons of copper in 1991, according to the company annual report. The fire that shut down the Cyprus Minerals Miami smelter stalled plans to resume mining at the company's mine near Pinos Altos, NM. Copper concentrates were stockpiled following the November 9 shutdown. A decline in zinc prices and the need to develop underground access to the copper ore body 300 feet lower were reasons given to shut down the Pinos Altos Mine in mid-July. Although the mine was shut, development continued on the new high-grade copper deposit, which was expected to provide at least 3 or 4 years of ore.

Cyprus Minerals spent about \$20 million on exploration during 1991, primarily in Australia, Canada, Chile, Mexico, Panama, the United States, and Venezuela. The company's long-term strategy was to enlarge its copper business and to go down the cost curve by developing a world class ore body. The company expected its exploration efforts to identify opportunities to develop economic ore bodies worldwide.

Formosa Resources Corp. started production from its Silver Butte Mine in Oregon, producing some zinc in addition to copper. The company was planning an expansion down dip in the deposit, expanding the lowermost drift.

Great Lakes Minerals had acquired five known chalcocite deposits along favorable stratigraphy in the Keweenaw district of northern Michigan. The company controlled about 200,000 acres of ground, including that previously

explored by Inco and Homestake in the 1970's. The largest deposit was the 543-S, which had reserves of 1.2 million tons of 4.41% copper and the G-2, which had 39,371 tons of 3.49% copper. Wheaton River Minerals of Toronto was to take an option for further exploration of the G-2. A feasibility study conducted in 1990 indicated the 543-S could be developed for about \$3 million. Noranda also took an option, agreeing to spend \$4 million in exploration over 4 years to earn 60% of 41,840 acres in Michigan from Great Lakes Minerals, which did not include the 543-S deposit. Since exploration was last done in this area in 1975, this was good news for copper exploration on the Keweenaw Peninsula.

The fourth mill line at Kennecott's Bingham Canyon copper mine was to start up in January 1992 and was expected to reach design capacity by mid-1992. During its first 5 years of operation, the new line was expected to add 32,000 tons of copper and 84,000 ounces of gold annually to the Bingham Canyon production. A total of \$219 million was invested in the new mill line.

Magma Copper was evaluating two major mine deposits, its lower Kalamazoo ore body, near the San Manuel underground mine, and its recently acquired Robinson Mining District. Although the company wrote off costs incurred by its former parent company in the Kalamazoo ore body, it has undertaken further studies to assess the economic viability of this property under current conditions. Extraction of sulfide ore from the San Manuel underground mine began in 1956, and about 99,790 tons of copper was produced in 1991, from 47,174 tons of ore per day averaging 0.67% copper.²⁸ The Upper Kalamazoo ore body consists of about 15.4 million tons grading 0.72% copper that can be economically exploited during the period covered by the current mine plan, based on 80-cents-per-pound mining costs. Although Kalamazoo development was suspended in 1984 owing to poor market conditions, it was restarted in 1986 only to be suspended again in October 1988; limited development resumed during the fourth quarter of

1989, reaching a production rate of 9,980 tons per day in December 1991.

Magma Copper's currently operating mining divisions are in southeastern Arizona and are the San Manuel Mining Div., Pinto Valley Mining Div., and Superior Mining Div. At San Manuel, copper is mined from an underground mine, an open pit, and an in situ operation. The Pinto Valley Mining Div. leaches mill tailings and conducts in situ leaching above an underground mine that is no longer in operation. The Superior Mining Div. mines and concentrates ore from its recently reopened underground mine.

The lower Kalamazoo ore body contains 273.1 million tons, but is not considered proven or probable reserves, and the company is currently evaluating whether any of these mineralized areas can be reclassified as proven reserves. This study is expected to be concluded by 1992. Subject to further feasibility studies, the company believes that the lower Kalamazoo ore body could produce about 77,110 tons of copper per year for 11 years. Sulfide ore from the underground mine is rail transported to the concentrator, which produces a 30% copper concentrate along with molybdenum disulfide as a byproduct. The concentrator has a rated capacity of 56,700 tons of ore per day, but during 1991, the concentrator processed an average of about 49,714 tons of ore per day, including reprocessed smelter slag and purchased ore. During 1991, about 11.8 million tons of copper oxide ore, averaging 0.373% acid soluble copper, was mined and separated from waste materials. The stripping ratio at the open pit mine was 2:1, waste to ore mined. The oxide ore was arranged on lined leach pads, and a water and sulfuric acid leach solution was sprayed over the ore.

Based on a recently completed reserve audit and resulting changes to Pinto Valley's Mine Plan and after giving effect to 1991 production, the open pit sulfide proven/probable reserves were lowered to 160.5 million tons from the estimate of 322 million tons of a year ago, according to Magma reports. Increases in productivity and cost improvements over

the next several years could result in reclaiming of all or a portion of these lost or reclassified reserves. During 1991, Pinto Valley produced about 20.9 million tons of ore with an average grade of about 0.386% copper. The stripping ratio was about 1.5:1 and will remain near that level until the late 1990's, after which the stripping ratio will fall sharply when mining sulfide ore at the open pit mine will be in its last phases. According to the company annual report, the Pinto Valley concentrator produced about 239,497 tons of concentrate. Low-grade copper-bearing waste is transported to large dumps that are then sprayed with water and sulfuric acid for leaching and treatment through an SX-EW plant. Pinto Valley produced about 6,804 tons of copper cathode in 1991.

Magma Copper continued its reclamation project started in 1988 for leaching of mill tailings at the old Miami underground mine. The tailings were reclaimed using hydraulic mining methods to produce a slurry of tailings and water. Sulfuric acid is added to the slurry to dissolve the copper and the leach solution is processed through the Miami Unit's SX-EW plant. The tailings are disposed of by pipeline to an abandoned Miami Unit pit. During 1991, about 3.5 million tons of tailings was mined, producing almost 4,082 tons of copper, according to the company annual report. Production was expected to continue until 1998 from this project.

According to the company annual report, about 10,886 tons of copper was produced from ore mined at the Superior Mine. In November, a fire occurred at the mine that curtailed production for most of November and all of December and resulted in a charge to cost of sales of \$2.2 million for 1991. At a production rate of 908 tons of ore per day, the Superior Mine had an estimated mine life through early 1997. Magma was evaluating an expansion of the mine to 1,360 tons per day. The evaluation was expected to be complete by mid-1992.

Magma completed a series of transactions for the acquisition of the Robinson Mining District near Ely, NV.

Development of the Robinson Mining District was to be conducted through the Robinson Mining Ltd. Partnership. The two owners of the Robinson Mining Ltd. Partnership were wholly owned subsidiaries of Magma; i.e., Magma Nevada Mining Co. was the general partner and Magma Ltd. Partner Co. was the limited partner. Based on a feasibility study, reserves were reported to be 182.3 million tons with average 0.61% copper and 0.010 ounce per ton gold. The mine could produce for 16 years at a rate of 56,700 tons of copper annually, at an estimated cost of about 57 cents per pound. Another feasibility study is under way to determine potential use of SX-EW methods, expected to be complete in 1992. Magma expected full production to start by the end of 1994, subject to necessary permits, financing commitments, and other factors.

According to the company annual report, Phelps Dodge's U.S. mines and related facilities produced 564,100 tons of copper, including 212,372 tons of copper from SX-EW operations. Eventually, the company expected SX-EW production to account for about 50%, or about 226,796 tons, of company production annually. This production is a major factor in lowering production costs. In 1991, ore and rock mined at Phelps Dodge facilities was as follows, in thousand tons: Morenci, 179,631; Tyrone, 83,953; and Chino, 93,620. A total of 357.3 million tons of material was mined at Phelps Dodge's domestic properties; total ore milled amounted to 69.3 million tons with an average grade for Morenci of 0.74% copper; for Tyrone, 0.79% copper; and for Chino, 0.67% copper. Chino produced 92,714 tons of copper in concentrate and precipitate and 50,077 tons of SX-EW cathode. In addition, precipitate production at Bisbee was about 91 tons.

The Morenci Mine, AZ, is the largest copper producer in North America and the second largest in the world, after Chuquicamata, Chile. The mine consists of two open pits, two concentrators, and an SX-EW plant. The two pits, the Morenci and Metcalf, are on two sections of the same deposit. Phelps Dodge owns

85% and Sumitomo Metals of Japan owns 15% interest in this mine. During 1991, Morenci produced a record 310,439 tons of copper. The company continued to study feasibility for mining the recently discovered Coronado deposit at Morenci. The Coronado deposit contains 163.3 million tons of sulfide ore at a grade of 0.71% copper and 272.2 million tons of leachable ore containing 0.29% copper.

Construction continued on the Northwest Extension project, which will add 63,500 tons of SX-EW copper cathode production annually. With this addition, the Morenci SX-EW plant would be the largest in the world with an annual production capacity of 154,200 tons per year of high-grade cathode copper. The Tyrone SX-EW plant was to be expanded in early 1992, with annual production capacity increasing from 49,900 tons to 63,500 tons annually. The Tyrone plant was expected to operate for at least 10 more years.

Chino Mines Co., a subsidiary of Phelps Dodge (two-thirds owner) and of Mitsubishi Corp. (one-third owner), operated an open pit, concentrator, and SX-EW plant in Santa Rita, NM. Chino produced a record 140,977 tons of copper, of which 50,077 tons was SX-EW cathode, according to the company annual report. A two-stage SAG mill discharge, pebble-recycle crushing was installed to increase throughput.

In early 1992, Phelps Dodge suspended indefinitely concentrator operations at the Tyrone Mine, NM, because the sulfide copper ore reserves had been substantially depleted. The company will continue to mine only material needed for leaching and for keeping the SX-EW plant at capacity. SX-EW capacity was to be expanded to 63,500 tons annually by 1992. Low-grade oxide and sulfide ore will be mined for its SX-EW facilities for about 10 years.

Phelps Dodge's 1991 exploration program targeted copper as well as other base and platinum-group metals. The company spent \$36.3 million, compared with \$33.1 million in 1990. About two-thirds of these expenditures was spent in the United States, but also

included were exploration efforts in Botswana, Canada, Chile, Costa Rica, Mexico, and the Republic of South Africa. Drilling at the Tyrone Mine in New Mexico resulted in identification of 91 million tons of leachable copper ore with an average grade of 0.35% copper. This will enable extension of the SX-EW operations at Tyrone for several years. The exploration group also continued to evaluate copper resources in the Safford District of Arizona. The Lone Star Deposit, which contains 1.45 billion tons of leachable material at a grade of 0.38% copper, and the Dos Pobres deposit, containing about 208.7 million tons of leachable ore with 0.48% copper, was further drilled for potential. Bulk sampling and testing of the Cochise project near Bisbee continued. If brought into production, Cochise could produce 36,300 tons of copper annually for about 10 years.

Phelps Dodge completed several major projects of a 3-year program to extend mining operations into new areas near its Morenci open pit in Greenlee County, AZ. Expansion into the Northwest Extension and reentry into the dormant Metcalf pit north of Morenci will provide ore after ore reserves in the 54-year-old Morenci pit are depleted sometime in the mid-1990's. Mining in the Northwest Extension started in 1989 and will provide about 907,200 tons of copper during the mines life, mostly as cathode from the SX-EW plant. The ore body is an oxide cap over sulfide reserves, with the oxides accounting for two-thirds of the reserves. State Highway 666 had to be relocated, which was completed in August 1991, allowing stripping of overburden. Sulfide mining will follow at a later date. Once the area is mined out, it will be used as a storage area for stockpiling low-grade ore from Metcalf, reducing overall mine operating costs during the latter stages of Metcalf pit mining. The Metcalf Mine was started in 1974, but shut in 1980 owing to weak copper prices. The 3-year expansion at Morenci increased production by 142%.

The Metcalf pit was originally estimated to contain 377 million tons of ore grading 0.77% copper, and while

comparable to Morenci, will require twice the stripping before it can be mined. Production from the Metcalf operation will be gradually increased as reserves are depleted in the Morenci pit during the next 4 to 5 years. The mining rate will eventually be 158,757 tons per day. The combined operations will produce about 521,631 tons per day. Several large construction projects were undertaken to mine the Metcalf ore. This included a two-phase expansion of the Morenci in-pit crushing and conveyor system (IPCC) to link the new ore source with the mills, a new truck shop for larger equipment, and improved water and electrical distribution systems. The IPCC system incorporates crushing, conveying, and reclaiming. The crushing plant includes two semiportable crushing stations and several conveyor belts that transport the minus 8-inch crushed ore from the pit to storage areas. In the second phase, scheduled for completion in 1992, conveyors will be installed to deliver ore from Metcalf to storage southeast of the Morenci pit.

Plexus Resources Corp. (51% Total Energold) filed a production plan with the Forest Service and engaged a contractor to do an environmental impact study (EIS) for the Bornite deposit, Oregon. The EIS was expected to be complete by yearend 1992. Plexus budgeted 1992 funds to complete the predevelopment work required for mine permitting at its Silver Star property in Washington. The 1983 feasibility study conducted by the former owner, Silver Star, was being updated. The deposit had 2.6 million tons of 1.81% copper and 0.035% molybdenum. An open pit mine was planned.

The Absaroka Mountains of Wyoming were discovered to have two porphyry copper-silver deposits that lie outside the wilderness area. These are the Kirwin and Sunlight Basin porphyries south of Cooke City, MT, and were receiving interest by some companies. The area is a deeply dissected Tertiary volcanic plateau.

Smelter Production.—Primary smelter production was at about the same level as

that in 1990. Eight primary smelters and a smelter-level SX-EW plant had a combined capacity of 1.37 million tons during the year. Included with primary smelter capacity was the Lakeshore roast/leach plant that processes concentrates from Cyprus Minerals' mines. In addition, five secondary smelters and a small 450-ton-per-year secondary electrowinning plant had a combined capacity of 441,450 tons. U.S. smelter capacity was expected to begin an upward trend over the next several years as a result of expansions planned for the El Paso, TX, Miami, AZ, San Manuel, AZ, and Garfield, UT, smelters. A total of 171,000 tons of new primary capacity was expected to be on-stream by 1995. The new smelter project for Texas City, TX, was expected to be canceled in 1992 because of stringent environmental requirements. Cerro Copper Products declared a force majeure for 2 months while it repaired a floor collapse in its secondary furnace.

The growing world shortage of copper smelter capacity presented an opportunity for Copper Range, which had extra smelter capacity. Copper Range planned to use this extra smelter and refinery capacity and, as of late 1991, the company was negotiating for toll concentrates.

Expansion and modernization of the Miami, AZ, copper smelter was slated for midyear 1992 completion by Cyprus Minerals. The project was to cost \$106 million and was to increase Cyprus Minerals smelting capacity by 50%. The smelter was shut down in November 1991 for repairs following a breakout of molten copper and the resulting fire. Production was to resume in March 1992 using the rebuilt electric furnace. By July 1992, the new Isasmelt furnace was expected to begin operation, gradually increasing until the full 589,670 tons per year of concentrate would be reached in 1993. Cyprus Minerals planned to stockpile concentrates while its smelter capacity was down with about 145,150 tons of concentrates treated through its roast/leach facilities at Lakeshore, AZ. Magma Copper was planning a 49,895-ton-per-year copper expansion at its San

Manuel smelter. The \$60 million expansion would involve removing the flue dust from the smelter and treating it at the SX-EW plant, increasing electrowinning output by about 11,793 tons per year, adding a third converter, and constructing a third acid plant. The project would be complete by early 1993.

Magma Copper Co. operated the largest and most modern copper smelting and refining complex in the United States. The smelter had a rated production capacity of 900,000 tons of copper concentrate per year, representing about 25% of U.S. smelting capacity, according to the company annual report. The company smelted and refined concentrates on a custom basis in addition to that generated from its own mines. Magma's total smelting production increased by 38% between 1988 and 1991. Magma was further evaluating another expansion of its smelting and refining complex to take advantage of a worldwide shortage of processing capacity. As a result of this apparent shortage, combined smelting and refining charges increased by more than 100% over the past year. Magma planned to expand its existing smelting and refining complex by 20% for a significantly lower cost and shorter construction period than that required for a new facility with the same capacity. Magma smelted and refined about 251,290 tons of concentrates on a custom basis. In 1991, the smelter processed about 913,535 tons of new sulfide concentrate, according to the company annual report.

Phelps Dodge smelted a total of 277,327 tons of copper in 1991 from its two smelters at Chino Mines Co. and at Hidalgo in New Mexico, according to the annual report.

Refinery Production.—Ten electrolytic, 6 fire refineries, and 14 electrowinning plants operated during the year. Total U.S. refinery capacity was 2.55 million tons of copper. Refinery production from primary sources increased markedly as a result of a 20% increase in SX-EW sources, but production from primary blister was down owing to temporary smelter

closures. Refined copper from scrap was also lower. Refined imports were higher, but exports were still markedly higher than those in 1990.

Cyprus Minerals continued to increase its copper leaching operations with expansions at Bagdad, Mineral Park, and Sierrita. A copper leach project was also under study at Tonopah, NV. Cyprus Minerals produced the first SX-EW cathode from its Bagdad Mine to meet the stringent specifications for trading on the LME and COMEX. Cyprus Minerals produced 95,255 tons or 33% of its annual production from SX-EW production technology.

Over the past few years, Magma Copper has increased the amount of copper sold in the form of cathode and decreased that sold as rod from 65% of total in 1989 to 32% of total copper sold in 1991. The company planned to increase the percentage rod sales for 1992. Magma has also increased its exports in recent years to fabricators in expanding Asian markets. Export sales, as a percentage of total revenues, were 50% in 1991, compared with only 28% in 1989. The company formed a new subsidiary, Magma Metals Co., to operate its smelting and refining complex and its rod plant and to conduct its sales and marketing activities. In 1991, Magma refined 259,909 tons of copper anode. Precious-metal-bearing residues were recovered and sold to third parties for recovery. The refinery was expanded to 272,000 tons per year from 227,000 tons per year of capacity as part of the company's expansion and modernization program.

At San Manuel, the in situ program was adversely affected by ground movement attributed to underground mining. Open pit mining activities also limit the areas available for in situ operations. Haulage roads and waste stripping activities will occasionally require that in situ activities be terminated until open pit mining activities have progressed through a specific area. Despite these constraints, in situ production during 1991 and 1990 at San Manuel totaled almost 11,340 tons of copper, as compared with about 4,082

tons in 1989. The in situ leaching is done through injection of acid leach solutions into holes 700 to 1,200 feet deep. The solution is percolated through rubblized oxide ore where the copper is dissolved and pumped to the surface for SX-EW processing. In the SX-EW plant, the pregnant leach solution is processed into copper cathode. In the solvent extraction process the leach solution is mixed with an organic reagent to extract the copper and then with an acid electrolyte to transfer the copper to the electrowinning solution. Stainless steel plates are used for starter sheets. The plant produced 43,545 tons of copper in 1991.

According to the company annual report, about 15,876 tons of copper was produced by the two Pinto Valley SX-EW facilities. In 1991, copper ores milled by the Pinto Valley Div. accounted for about 65,771 tons of copper cathode refined by the company.

Phelps Dodge Corp. produced 350,173 tons of refined copper in 1991 at its refinery in El Paso, according to the company's annual report.

Cerro Copper Products Co. declared a force majeure in April on all shipments of copper cathode from its electrolytic copper refinery in Sauget, IL, while it repaired damage to its casting facilities. Production was disrupted for about 2 months.

Copper Powder.—Copper powder production at U.S. ingotmakers, foundries, and miscellaneous manufacturers reached 17,400 tons in 1979, but has declined sharply since that time by more than one-half. Copper powder production in 1991, at 7,794 tons, also was down by 8.6% from that of 1990. At the same time, copper powder imports have increased since 1983 to about a 1,400-ton-per-year level. Nonetheless, exports, which were also lower by one-third in 1987 and were lowest in 1983 and 1984 compared with those of 1979, have continued to be relatively high and were nearly double the amount imported. Continued high exports, coupled with a decreased domestic production, have led to a

decrease in U.S. apparent consumption of copper powder from 16,692 tons in 1979 to about 7,500 tons in 1991. Powder metal sales, including copper powder, in North America were heavily dependent on the automotive industry, which decreased the number of vehicles shipped over the same period.

Copper powder consumption was reported from 18 companies in 1991, 35 companies in 1987, and down from 42 companies in 1986. Among the companies reporting to the U.S. Bureau of Mines, the largest consumers were General Electric Co., St. Mary's Carbon Co., Allied Signal Co., Atlantic Sintered Metals, Stack Pole Corp., Presmet Corp., and Precision Metal Products.

Copper powder usage, including bearings, comprised about 48% of major copper and copper-base powder markets, the total shipments for which amounted to about 16,239 tons in 1991, according to Metal Powder Industries Federation data. Probably the best known use for copper powder was the self-lubricating bearing that was the first major application, which still counted for about 70% of the granular copper powder used. Copper and copper alloy powder was used in the automotive and aerospace industry for brake linings and bands, bushings, instruments, and filters. Pure copper powder was also used in the electrical and electronic industries. Ultrafine powder has been developed to meet requirements of thick film electronic circuit applications. Copper powder in flake form was used for antifouling paints, decorative and protective coatings, and printing inks. Nonstructural applications included brazing; cold soldering; mechanical plating; metals and medallions; metal-plastic decorative products, such as floor tile and epoxy resins; fungicides; soil conditioning; and various chemical and medical purposes.

The top four copper and copper alloy powder producers were Alcan Metal Powders, Greenback Industries, Inc., U.S. Bronze Powders, and SCM Metal Products. SCM closed its Hammond, IN, plant in 1986, but continued to operate its Indianapolis, IN, Durham, NC, and Johnstown, PA, plants. The value of

U.S. copper powder production comprised only about 2% of the total metal powder sales in the United States, which amounted to almost \$1 billion. Commercial-grade copper metal powder prices were \$1.49 to \$1.61 per pound on June 5, 1991, down from prices of \$1.60 to \$1.70 per pound at yearend 1990, reflecting adjustments for the cost of copper.²⁹

Granular copper powder can be produced by a number of methods, including atomization, electrolysis, hydrometallurgy, and solid-state reduction. Each method yields a powder having certain inherent characteristics. Atomization was the preferred commercial production technique used because the powder chemistry, cleanliness, size, and shape can be better controlled with this method than with other methods.

Copper Sulfate.—Copper sulfate was produced from copper scrap, blister copper, copper precipitates, electrolytic refinery solutions, and spent electroplating solutions. Imports of copper sulfate, which have more than doubled since 1987, were accounting for an increased share of U.S. consumption. Exports were also marginally higher. The major copper sulfate producers of Europe were France, Germany, Italy, and Poland. Japan and the Republic of Korea were the leading Asian producers. Copper sulfate was used as an algicide and fungicide and as a source of copper for plant and animal feed. Industrially, copper sulfate was used to activate zinc and other sulfides in froth flotation; as a print toner in photography; as a stabilizer and in blue and green pigments; in copper plating baths for electronics, metal finishing, and in pickling baths; and numerous other chemical applications. Large crystal copper sulfate had special application in water treatment where it was used as a water purifier in municipal water supplies and other treatments. Domestic demand for copper sulfate had risen steadily since 1987 owing to increased use in agriculture.

Sulfuric Acid.—Byproduct sulfuric acid (100% basis) produced in the United States was up significantly to about 4.4 million tons, an increase of 42% since that in 1987. Even so, Phelps Dodge reported lower sulfuric acid production (1,180,883 tons) in 1991, compared with 1990 (1,205,467 tons), according to the company annual report.

Prices

When spot copper prices closed at \$0.98 per pound on the COMEX on July 1, in the middle of a weak U.S. and global economy, some analysts predicted that the bull market that has existed since 1987 was over. Some traders were predicting prices lower than \$0.80 per pound, but 3 months later, the COMEX price settled at \$1.07 per pound and the 3-month spread on the LME was in backwardation. Despite supply problems, U.S. refined copper stocks were 30.4% higher by yearend. December ended with an average \$0.98 per pound on the COMEX, but supply problems seemed to be persistent as Zaire's production, in particular, took a strong drop. Smelter constraints were also responsible for restraining an even flow of metal to the market, and as the U.S. economy began its recovery at yearend, copper prices above \$1.00 per pound seemed to be inevitable.

Smelter charges were high all year. The treatment and refining charges (TC/RC's) were driven up to the equivalent of \$0.26 to \$0.29 per pound of copper.

Consumption

U.S. consumption of copper was down by 4.3% compared with that of 1990, reflecting the economic recession until late in the year. In the United States, Western Europe, and Japan, the principal growth sectors were in construction, transportation, and engineering applications. The U.S. competitive position improved during the year with increased exports as a result of strong demand growth in Asia, creating a dramatic shift in the U.S. balance of

trade. U.S. exports of concentrates, refined copper, and semifabricates all improved during 1991. U.S. net imports of brass mill semifabricates decreased for the seventh consecutive year, having reached a peak in 1984.

Demand from nearly all of copper's end-use markets increased by yearend, but none experienced the kind of increase that occurred during the late 1980's. Sales of rod and wire to the automobile and construction markets increased substantially in September and October. Ammunition was Outokumpu American Brass's biggest growth market because of the Persian Gulf war. According to copper and brass distributors, demand for some copper used for military hardware jumped up fourfold as a direct result of the Persian Gulf war. Substantial increases were indicated in nickel-aluminum bronze used in landing wheel bushings, as well as for electrical connectors used in computer circuitry, copper rounds, naval brass, and 660 bronze alloy for use in general rebuilding of military vehicles and equipment.³⁰

Chrysler Corp. announced that its next generation of small cars due out in 1994-95 would use copper radiators. The radiators were to be supplied by a Japanese contractor rather than by the Chrysler plant in Dayton, OH, which had been the automaker's principal supplier of copper radiators for years. The supplier was to be the Japanese-owned Nippondenso Manufacturing, USA Inc., at Battle Creek, MI, which purchased most of its copper from subsidiaries of Outokumpu Oy in Sweden. The new radiators were thought to weigh 10 to 11 pounds each.

According to the National Association of Home Builders, more housing starts were seen as underlying an expected copper consumption increase of 27% for the construction sector in 1992. After reaching a peak in 1986, housing starts have been in decline every year, but 1992 was expected to reverse this trend.³⁰ As shown in figure 10, copper consumption by tube manufacturers has generally followed the index for housing starts since 1983. An important departure from housing started in 1986 with copper

consumption at copper tube mills increasing despite the dropoff in the number of housing starts. This was in large part caused by the increase in copper plumbing tube per unit, as houses increased in size and required more bathrooms and ancillary features, as well as of increased use in industrial buildings for sprinklers and other systems. This trend also reflects the increased exports of copper tube and pipe since 1986, which have increased by almost 280% to 20,240 tons in 1991. Net imports of copper tube have steadily declined since 1986 and, in 1991, the United States became a net exporter, as shown in figure 11. Canada (8,000 tons), Mexico (2,000 tons), and Saudi Arabia and Spain (each with 1,000 tons) were principal recipients of U.S. tube among 57 countries. (See figures 10 and 11.)

According to recent reports by the Copper Development Association (CDA), modest growth was occurring from both recaptured markets, most notably building wire, magnet wire, air conditioner tube, transformer winding strip, and bus systems, and from new market growth in electrical and electronic markets, plumbing, heating, and cooling applications. Since the rapid aluminum substitution of the 1960's and early 1970's, because of its efficiency and reliability, copper had reestablished its position in electrical wire applications. Aluminum, while retained for overhead power cable, was soundly rejected for building wire. The electrical end use sector had been the fastest growing sector in the United States and, in 1991, comprised 75% of copper consumption.

Changes in copper consumption trends included a significant drop in the end-use category "other uses," from 6% to the current 3% of the total, which followed the capture of the penny by zinc in 1981. Despite heavy substitution by other materials such as plastics and aluminum, copper consumed for the nonelectrical construction sector decreased little compared with higher losses in other sectors such as the nonelectrical transportation and machinery sectors in the United States. With failure of plastics in some water pipes and increased use of

copper for sprinkler systems, copper was making a comeback in some sectors of the country. Homes were increasing in size, and CDA data indicated that there was a concurrent increase of copper usage to 279 pounds of copper wire per average new house. This was about a 20% increase in copper consumption per average house over the past 10 years.

AT&T Network Cable Systems, in reviewing fiber-optics substitution for copper from a telecommunication company's perspective, concluded that as technology advances, better ways to use copper were being discovered and copper usage in the telecommunication industry was again on the rise. The company concluded that copper's demise in the telecommunication industry has been oversimplified, for while the process of fiber-optics replacement and the use of more efficient, smaller wires and multiplexing was undeniable, new networks were being installed for facsimile (FAX) machines, data systems, and cellular phones. These new growth areas, while less visible, have had a positive effect on the growth of copper in telecommunications in recent years. Insulated wire and cable shipments have increased since 1986, though the decline in copper telecommunications consumption between 1980 and the low point of 1986 was significant. This decline was anticipated to pick up speed in the late 1980's, but this trend never materialized. There reportedly was 3.5 million tons of copper in local U.S. telephone networks and replacing that copper will take time, because the copper infrastructure was reliable and cost efficient and it would be financially unwise to rip it out to replace it with fiber.³² (See table 7.)

World Review

Industry Structure.—Market Summary.—In recent years, supply has been running below demand levels, but in 1991, against a background of lower demand, world production of copper from mines and refineries was generally higher than demand. Excessive levels of world stocks were built up in the 1970's and

1980's, reaching as high as 6 months and 3 months of consumption in 1975 and 1983, respectively. However, by 1987, this excess had been eliminated, and stock levels retreated to less than 1 month's consumption. Since 1989, industry output has been constrained by an almost continuous string of major production disruptions because of civil unrest, strikes, and technical difficulties. Notable among the disruptions was the shutdown of the Bougainville Mine, regular strikes in Peru, production difficulties and strikes at two large Chilean mines, and a variety of problems in the African Copper Belt, particularly Zaire. The result has been, that by 1991, the significant increases in new mine production were nullified by production losses through reserve depletion, lower grades, industry deterioration, and disruptions.

The complete drawdown of refined stocks by 1987 resulted in a rapid increase in the copper price. U.S. producer copper prices have since fallen back from the high average of \$1.31 per pound for 1989 to an average \$1.09 per pound for 1991, in response to slower economic growth and a modest increase in inventories. As the world drew into a slower economy at yearend 1991, world refined stocks were 969,000 tons, a 42% increase compared with those at yearend 1990. Most of the stock increases took place on the exchanges. Refined inventories on the LME and COMEX totaled 330,000 tons and 30,000 tons, respectively, an increase of 84% compared with those at yearend 1990 for the two exchanges. An excessive backwardation tended to attract inventories to the LME at yearend; in contrast, the increase in COMEX stocks occurred earlier in the year, after which they remained fairly stable.

Fourteen mining companies joined to form the International Council on Metals and the Environment (ICME), headed by Noranda Minerals Inc. The organization was an effort to coordinate industry knowledge, experience, and resources to address international issues. The industry anticipated becoming more active in helping to develop and implement sound

environmental and health policies and practices.³³

Mine Production.—New Capacity.—World mine capacity totaled 10.7 million tons in 1991, including 363,000 tons of capacity from 10 new mines started in Australia, Canada, Chile, China, Colombia, and Portugal. The large La Escondida Mine (310,000 tons per year) in Chile had its first full year of production in 1991. In addition, several operating mines expanded capacity, resulting in a total world mine capacity increase of 4.7% compared with that of 1990. Even so, although U.S. copper mine production expanded by 2.7%, world mine production only increased by 1.5%, representing a capacity utilization of only 79.3%, an alltime low capacity utilization rate. Development was also started on several mines, accounting for about 89,000 tons expected to come on-stream in 1992 from 15 small mines in Australia, Botswana, Canada, Chile, China, the Republic of South Africa, Turkey, and the United Kingdom.

Australia.—Straits Engineers Contracting and Nord Pacific Ltd. (40%) formed a joint venture at yearend 1991 for the development of the Girilambone Deposit, New South Wales. The deposit has 4.3 million tons of 2.4% copper ore and some gold. A 16,000-ton-per-year copper mine was planned. Construction and engineering contracts were being negotiated. Mount Isa Mines Co. (MIM) planned to spend \$165 million on expansions and improvements to its Mount Isa copper facilities, including two semiautogenous (SAG) mills that were commissioned at the copper concentrator in 1991, reducing milling costs, and a fine-grinding project to boost recoveries for lead, zinc, and silver at the zinc concentrator.

Denehurst Ltd. began development of the Benambra copper mine in the State of Victoria, Australia. Output would be about 70,000 tons per year of concentrates with an average grade of 27% copper. Production was scheduled for November 1992. Furukawa Corp. owns 11.66% of Denehurst. Most of the

mine's output would be processed at Southern Copper's Port Kembla smelter refinery, owned 30% by Furukawa, 10% by Nissho Iwai, and 60% by CRA Ltd. The balance would be exported to Japan.

Canada.—The Goldstream open pit and underground mine at Revelstoke, BC, reopened in May 1991. Nippon Mining and Sumitomo provided \$7 million to allow the owners, Bethlehem Resources and Goldstar, to reopen the mine. The mine, closed since April 1984, was rehabilitated to produce 16,000 tons of copper. Reserves were 1.86 million tons of 4.81% copper and 3.06% zinc, sufficient until 1996.

Near the BHP-Utah Island Copper open pit, Moraga Resources and Crew Natural Resources identified two copper deposits, Expo and Red Dog, containing 143 million tons of 0.32% copper and 47 million tons of 0.32% copper, respectively. These deposits could provide ore for the concentrator beyond 1996. The open pit at Island Copper was deepened by a further 145 meters to extend the life of the reserves that were scheduled for exhaustion in 1991. The pit was 2.3 kilometers long and 1 kilometer wide with present bottom at 245 meters below sea level.

The Gibraltar Mine was owned 8.1% by Placer Dome Ltd. and was at Williams Lake, BC. The open pit produced 28,755 tons of copper in concentrate in 1991 and 3,331 tons of SX-EW cathode. Although output was slightly below that of 1990, it was expected to increase in future years as higher grade ore is mined from the new Gibraltar East ore body. Development of the Gibraltar East began in 1991. Costing about \$17 million, the mine will last for about 5 years and will offset loss of ore from the Pollyanna pit that is scheduled to close in early 1993. The mine has reserves of 150.4 million tons of 0.312% copper, enough for about 12 years. Placer was drilling on the adjacent Gibraltar North Zone, following an agreement with New Coast Silver Mines to amend a royalty agreement.

In 1991, the Trout Lake and Calinan underground mines produced 83,000 tons of concentrate grading 20.5% copper, in

addition to zinc. At the Trout Lake mine a shaft development was completed in mid-1990 that enabled mining rates to be increased to more than 800,000 tons per year of ore by 1995.

In October 1991, Inco completed the consolidation of its milling and concentrating operations in the Sudbury, Ontario, area at a cost of \$57 million. The Clarabelle mill was modernized and expanded to 40,000 tons per day of ore by the addition of a SAG mill and large flotation cells. The older Frost-Strobie mill was closed in 1991, and the Copper Cliff mill is scheduled to be closed in 1993. Inco's Lower Coleman Mine was started up in 1991 and will reach full capacity of 3,000 tons per day of ore in 1993. Development on the McCreehy East Mine will resume in late 1992 with production scheduled for early 1994. Inco's Birchtree Mine, which has been on standby since 1977, was to be expanded by 50% and the new Thompson I-D Mine started by 1994; both of these were primarily nickel.

Minnova was to start development of its new Izok Lake zinc-copper deposit in the Northwest Territories by 1993. Metall Mining also acquired a 40% stake in the project for \$15 million. The deposit had reserves of 13.5 million tons of ore grading 14.4% zinc and 3.2% copper. Production might start as early as 1996.

Westmin's Myra Falls operation on Vancouver Island, BC, produced about 20,000 tons per year of copper. The H-W and Lynx Mines feed the Myra Falls mill, with more than 90% from the H-W. Column flotation cells were installed in 1991. In exploring for new reserves, drilling intersected significant sections in the Cap Zone, and the company began development access in mid-1991. Grades of 2.3% copper and 20% zinc were intersected.

Prior to being purchased by Princeton Mining, the Similco Mine was scheduled for closure in 1990, but the company revised the mining plan. Production in 1991 was from the No. 1, No. 3, and Virginia pits. The Virginia pit was brought into production in 1991 and had reserves of 6.3 million tons of 0.38% copper. Additional reserves were being

evaluated as was the recently discovered Alabama deposit, an extension of the Virginia pit.

Bitterroot Resources acquired an option to earn a 50% interest in the Lac Minerals Copper Giant project of British Columbia. With reserves of 244.9 million tons containing 2.06% copper and 0.0045 ounce/ton gold, the deposit was being further evaluated for an open pit.

Aur Resources Inc. announced in October that the final feasibility study for its 55%-owned Louvicourt deposit in northern Quebec confirmed its viability. Costing \$326 million, production could start in 1994 and produce about 55,000 tons per year of copper, 17,000 tons per year of zinc, as well as gold and silver. Reserves were estimated at 39 million tons of 3.3% copper, 1.8% zinc, 21.6 grams per ton of silver, and 0.7 gram per ton of gold.

Chile.—Compania Mineral Ojos del Salado, S.A., a wholly owned Chilean subsidiary of Phelps Dodge Corp., operated two underground copper-gold mines and a concentrator near Copiapo in northern Chile. With the completion of an \$18 million expansion project in November 1991, Ojos del Salado produced a record 18,144 tons of copper in concentrate. This was the second expansion at the mill, doubling processing capacity from 1,724 tons of ore per day to 3,493 tons per day.

La Candelaria, a major copper-gold deposit, was 3 miles southwest of Ojos del Salado near Copiapo in the Atacama desert. Ore reserves were about 362.9 million tons containing an average of 1.1% copper and 3 million ounces of gold. In June 1991, Sumitomo Metal Mining Co., Ltd., and Sumitomo Corp. agreed to invest a 20% interest in La Candelaria. Phelps Dodge expected the project to produce about 91,000 tons of copper and 80,000 ounces of gold annually by the mid-1990's. This deposit was discovered in 1987 by Phelps Dodge. Phelps Dodge anticipated spending \$90 million on the Candelaria project in 1992, having spent \$20 million in 1991. The corporation expected to fund La Candelaria expenditures with borrowing

by the subsidiary that owned the project, which was to be guaranteed by the corporation only until the project was completed.

CODELCO-Chile planned to develop Quebrada Teniente, a 56-million-ton deposit with an average ore grade of 1.4% copper to offset uncertain production from El Teniente's sublevel 6. Quebrada Teniente was expected to take 3 years to develop and cost about \$42 million, but to produce about 55,000 tons per year of copper. Exploitation of the Inca level of the El Salvador Mine was to begin in 1992. This level has reserves of 161 million tons of 0.6% copper.

Antofagasta Holdings (60%) and Outokumpu (40%) began production from their El Lince SX-EW project in Chile. The deposit contained 16 million tons of ore with 1.54% copper. Operating capacity was anticipated to be 19,958 tons per year of copper. The project cost \$63 million and began production in December. Ownership in 1991 was Chemical Bank (60%), Mineral Carolina de Michilla (25%), and Outokumpu Chile (15%). Chemical Bank's share was to be bought out in 1992.

North Lilly Mining began operations at its Tuina copper mine in Chile. The operation was a joint venture between North Lilly and International Mahogany, a Canadian subsidiary. Production was to be 6,260 tons of copper by 1992. The mine was an open pit, followed by heap leach. An SX-EW plant was being considered.

Outokumpu Oy of Finland planned for its Zaldivar Mine in Chile to start up in 1995 with a capacity of 100,000 tons per year of copper. The planned open pit mine has reserves of 560 million tons containing 0.62% copper, including a zone with 140 million tons grading 1.2% copper. Negotiations continued between CODELCO-Chile and Mineral Valle Central to option rights for processing the Cauguenes Tailings, which originated from the El Teniente Mine until 1977. A feasibility study was expected to be complete by June 1992.

At Chuquicamata, main pit reserves are in excess of 2.9 billion tons, sufficient for a minimum of 50 years of

production. In addition, Chuqui Norte, or Radomiro Tomic, 4 kilometers north of the main pit, was the subject of a feasibility study in 1991. CODELCO-Chile planned an open pit, heap-leach, and SX-EW operation. Total reserves there were about 2.5 billion tons of 0.625% copper, about 80% of which was oxide and leachable. Plans were for a 150,000-ton-per-year mine, with no timetable as yet for development. Mansa Mine, a deposit discovered in 1990 south of the Mina Sur open pit was also under investigation, as was El Abra, 40 kilometers north of Chuquicamata. An early feasibility study on El Abra indicated the potential for a 155,000-ton-per-year SX-EW operation. Reserves were estimated at 400 million tons of 0.7% copper.

CODELCO-Chile planned to spend \$264 million for developing the Mansa Mine. Projected to start up in 1998, at the rate of 60,000 tons per year of copper, Mansa Mine will be an open pit mine that will utilize Chuquicamata's concentrator. Total reserves were 990 million tons grading 1.1% copper, with a central body of 324 million tons of 1.15% copper. CODELCO-Chile's largest project, costing \$450 million, was the Radomiro Tomic. CODELCO-Chile hoped to begin mining the 691-million-ton copper oxide reserves, which grade 0.73% copper, by 1996 at the rate of 150,000 tons per year of copper. The third large item is expansion of the Andina Mine to 90,000 tons of new capacity by 1996, costing \$218 million. Four projects planned for El Teniente would provide a total of 234,000 tons of new copper capacity by 1998 and would cost \$248 million.

Cominco Ltd. announced that the Quebrada Blanca joint venture with Teck Corp. (32.5%), Cominco Resources (10%), ENAMI (10%), and Sociedad Mineral Pudahuel (5%) was to start construction of its \$300 million bacteria leaching, SX-EW project. Cominco Ltd. (42.5%) had completed metallurgical testing and detailed mine plans at yearend. Construction of the mine was to take almost 3 years.

Placer Dome (70%) and Equatorial Gold N.L. (30%) were close to financing the Leonor Mine development in Chile at yearend. The open pit mine was expected to produce almost 28,123 tons per year of copper in cathode, using heap leaching and electrowinning. Reserves were estimated to be 24 million tons of 1.6% copper.

Indonesia.—The Ertsberg, or Gunung Bijih deposit, was discovered in the Jayawijaya Range in 1936, but it was not until 1960, when Freeport Indonesia, Inc. reexamined the deposit, that serious consideration for development occurred. Freeport Indonesia became the first foreign mining company to arrange a mining contract with Indonesia after passage of the new Foreign Investment Law in January 1967. The mine underwent several expansions over the years, finally reaching 32,000 tons of ore per day. In 1989, it was decided to further expand facilities with the development of the nearby Grasburg deposit, and the 52,000-ton-per-day expansion was completed by November 1991. The Grasburg open pit is 2.2 kilometers to the northwest of the Gunung Bijih Timor pit. To date, about 675 million tons of ore has been identified. This reserve is expected to be expanded in the future by further drilling. The five Indonesian deposits, the Ertsberg, Intermediate Ore Zone (IOZ) and Deep Ore Zone (DOZ), DOM, and the Grasberg, were located along the southern edge of the highly deformed Papuan Fold Belt that runs east-west through much of New Guinea.

The Papuan Fold Belt is the result of northward-moving Australian Plate being subducted under a detached portion of the south-moving Pacific Plate. The composite reserve totals about 770 million tons of ore at 1.45% copper, 1.66 grams per ton of gold, and 3.86 grams per ton of silver. The Grasberg is the most significant of the five with an ore zone that is 500 to 600 meters in diameter. Two pipelines deliver the concentrate 113 kilometers to the port site for dewatering and shipping. The concentrate grades 34% copper, 15 grams per ton of gold,

and 55 grams per ton of silver. In 1991, 39 concentrate ships handled about 600,000 wet tons of copper concentrates.

Mexico.—In 1991, Mexican copper production dropped by 11%. A proposal to use heap-leaching techniques at the Cananea Mine was being evaluated as a way to lower costs from about 85 cents per pound to 40 cents per pound. Minera Maria, a new mine started last year, produced 40,285 tons of 12% copper ore.

South Africa, Republic of.—At Palabora, the feasibility of opening an underground mine once the open pit operations ceased was under study. Investments were also being made to improve environmental controls. The Palabora copper mine was considered to be one of the largest open pits in Africa and the world. The open pit measures 1.9 kilometers long and 1.6 kilometers wide at the surface. Open pit operations were expected to continue to 1999, when the mine will have been developed to a depth of 805 meters below the surface. A 4.8-meter-diameter shaft was sunk 560 meters to explore the possibility of underground mining. Construction could begin in 1994. Production would be phased in to maintain a stable level of ore to the crusher as open pit production declines.

United Kingdom.—Imperial Metals Corp.'s 30%-owned subsidiary, Anglesey Mining PLC of the United Kingdom, estimated its Parys Mountain Mine, North Wales, would have a mine life of about 15 years. Financing of the project was to be complete at yearend, with mine and mill construction starting in January 1992. Current reserves, at a net smelter return cut off of \$35 per ton, were estimated to be 6.45 million tons of ore grading 2.34% copper, 5.35% zinc, 2.6% lead, 39 grams per ton of silver, and 0.32 gram per ton of gold.

Zambia.—A number of mines and plants were closed in Zambia or put on care and maintenance, but still contain viable reserves. For example, reopening

the Chambishi Mine to selectively mine 2% copper ores was under consideration. In recent years, exploration has indicated that most of the steeply dipping ore bodies mined are flattening at depth, necessitating alternative mining methods. Use of fill mining methods was recommended for the Konkola Deep Mining Project, the Baluba Center Limb Project, and the Nkana Expansion Project. Columnar flotation cells have been installed or are planned for most Zambian concentrators. At Mufulira, the concentrate grade was raised by 3% to 48% copper through the use of columnar flotation. Columnar flotation for copper-cobalt separation was also planned to enhance depression of cobaltiferous pyrite. Recently completed hydrometallurgical projects included a circuit change at the Nchanga tailings leach plant that resulted in an extra 1,000 tons per month of copper.

The Konkola Mine, 25 kilometers from Chingola, has reserves of 47 million tons of 3.9% copper, but resources of about 380 million tons of 3.5% copper. Konkola (Bancroft) Mine is the wettest mine in the Copperbelt. In 1990, an average 348,146 cubic meters of water was pumped per day. Plans were to raise production from the No. 3 shaft to 100,000 tons of ore per month between now and 1993 for a total production of about 2 million tons per year. A \$400 million project was under study to raise Konkola production to 6 million tons per year. The project would take 7 years to develop and would involve sinking a new shaft to increase hoisting capacity.

Exploration.—In 1991, most industrialized countries were in a recession or a period of reduced growth. The U.S. economy, already in recession, suffered from mounting bank losses. However, U.S. and world mineral exploration did not collapse as it did during the mid-1980's. Even though base metal prices declined, prices were still above cash costs for most operations. This allowed the continuation of established exploration programs, but sharply limited new initiatives. Planned 1991 world exploration expenditures

declined by about 8% from 1990 levels, according to a survey of 153 companies by the Metals Economic Group (MEG). Canada was leading in the exploration area with 23%, the United States and Australia were 19% each; Republic of South Africa, 13%; Latin America, 11%; and southern Pacific, 7%, of the total exploration expenditures. The remaining 8% was split evenly between Europe and the rest of Africa. Mexico and Chile were reported as the most attractive in South America. Canadian Government estimates for 1991 Canadian expenditures were about 30% lower than those in 1990. The U.S. Bureau of Land Management (BLM) reported 1991 claims were 25% below the 1990 level.³⁴ Even though BLM claims were down, U.S. domestic exploration expenditures were higher compared with those of 1990. In the United States and elsewhere, the industry's renewed interest in base metals was reflected by the number of discoveries announced in 1991. Reported North American discoveries included: Mazama (copper-gold), Washington, by Centurian Mine; Lake Leo (polymetallic), Manitoba, by Granges; three new zones at Scott Lake (polymetallic) by Greenstone; Trout Lake (polymetallic) by Hudson Bay; Inco's Trout Lake, Victor; and McCreeley East polymetallic deposits and the Kemess South extension in British Columbia. Cominco reported success on the Cerrattepe copper deposit in Turkey.

Argentina.—American Resources Corp. was exploring the 298-square-kilometer property known as Campana Mahuida in the Neuquen Province of southern Argentina. Previous exploration by the Argentine Government had indicated copper and gold targets. American Resources, a Mill Valley, CA, company, was one of the first international mining companies to participate in privatization of Argentina's mining industry. Drilling had indicated 5 million tons of leachable copper grading 0.7% copper, occurring near the surface of a porphyry deposit. There was also 22 million tons of secondary-enriched sulfide mineralization that graded 0.63% copper. A joint venture was to be formed with

Campana Mahuida and American Resources for exploration and development. American Resources planned to spend \$1 million on exploration in the first year.

Also in Argentina, International Musto Explorations Ltd. completed its agreement with Yacimientos Mineros de Aguas de Dionisio, the optioner and 20% owner of the Bajo de La Alumbrera, Catamarca, deposit. Musto was to start an 18-month, \$4 million feasibility study in early 1992. The deposit contains 340 million tons of ore with 0.49% copper and 0.016 ounce per ton of gold. Production was planned for about 60,000 tons per year of copper.

Canada.—The South Kerness project was located in British Columbia and was being explored by El Condor Resources, a joint venture made up of Kennecott (40%) and St. Phillips Resources and Stork Resources (40%). The project was in the process of obtaining permits and a feasibility study. The date of startup for the 26,000-ton-per-year copper project was thought to be 1995. The porphyry deposit was reported to have reserves of 252 million tons grading 0.23% copper and 0.62 gram per ton of gold. The copper-gold mineralization was similar to Mount Milligan, a project that was canceled.

Located in northwest British Columbia, Windy Craggy was estimated to have total reserves of 297.4 million tons grading 1.38% copper and was clearly a world-class deposit. Open pit reserves would comprise about 118 million tons of 1.9% copper. In response to earlier concerns raised during the public review process, Geddes revised its original open pit mining plan to a combination of open pit and underground to reduce acid rock drainage and planned on pipeline concentrate transport. A feasibility study had been under way, but the environmental movement against the mine was considerable by groups seeking to stop development of the mine and to make the rugged and remote property part of a wilderness preserve where resource development would not be allowed. Land-use planning was

becoming an important aspect of the issue. The Windy Craggy Project was seen as an important first step in the development of the northwest corner of the Province. The fact that the mineral potential of the area for other base metals deposits was high was seen as particularly disturbing to those who would have no development in this area. Failure by Geddes Resources, 39% by Northgate Exploration Ltd. and 20% by Cominco Ltd., to win environmental approval would jeopardize other mining projects in British Columbia, particularly if opponents of the project succeed in having the area designated a wilderness preserve. Approval by the United States and the State of Alaska also was essential because concentrate would be shipped through Haines, AK, where a site also would have to be found for dewatering the concentrate. To succeed, this project not only will have to break new ground for sound environmental technology, but will also have to surmount diverse interests in land-use planning. The proposed project also was subject to the Canadian Federal assessment review process (EARP) because it affects several areas of Federal jurisdiction on fisheries and water quality. The project was becoming a highly emotional political issue. It was adjacent to national parks in both the United States (Glacier Bay National Park-St. Elias National Park) and in Canada, Kluane National Park Reserve. River-rafting companies using the Tatshenshini River opposed development in untouched wilderness. The environmental campaign was spearheaded by the Vancouver-based Western Canada Wilderness Committee. Even though the Tatshenshini River is miles from the mine site, the rafting expedition companies argued that a road and bridge would spoil the wilderness experience of the 200 tourists that go on rafting expeditions each year.

The Windy Craggy property was thought to be viable at \$0.80 per pound copper. Operating costs were expected to be about 25 to 30 cents per ton of ore mined, higher than Geddes had originally planned because of the special selection of explosives, reagents, tailings

impoundment, and effluent treatment. The operation would employ 600 to 650 persons and yield 140,000 tons per year of copper for at least 14 years with potential for another 15 years. The initial development would be an open pit, followed in 10 years by underground. The major environmental concern was the potential for acid drainage from waste rock. Other concerns included earthquake effects on tailings dams, the lifestyle change for Haines, Alaska, and impacts on the Chilkat Bald Eagle preserve. Trucking disturbances could be eliminated by buried concentrate slurry and fuel oil pipelines. Geddes estimates the total direct and indirect costs of the environmental review process to date were about \$5.5 million and that an additional \$10 million will be needed.

Inco Ltd. spent \$40 million on exploration in 1991 and made two major copper-nickel discoveries in its Sudbury, Ontario, district. Both new deposits also contained platinum, palladium, and gold, according to the company annual report. The Victor Deposit, north of Sudbury, contained between 18 and 36 million tons of ore. About 6.2 million tons was proven or probable reserves with copper values of between 5.11% and 7.37% copper and nickel values ranging between 1.49% to 2.61%. West of Inco's new McCreedy East Mine, another deposit was located that has 7.2 million tons of reserves, of which about 5.3 million tons was proven or probable ore that graded 8.83% copper and 0.63% nickel.

During 1991, Jordex Resources Inc. explored near Port Hardy, Vancouver Island, and acquired Moraga Resources Ltd. in August 1991. Work was done on the Hushamu deposit to earn a 45% interest from BHP-Utah Mines Ltd. and on the Red Dog property on which Jordex would earn a 50% interest from Crew Natural Resources Ltd. Open pit reserves at Hushamu were about 173 million tons of 0.25% copper, 0.3 gram per ton of gold, and 0.01% molybdenum, while the Red Dog had 45 million tons of ore grading 0.32% copper and 0.4% gram per ton of gold.

Exploration continued on the zinc-copper zones at Trout Lake Mine,

owned by Hudson Bay Mining and Smelting Co., Ltd. (HBMS), Granges Inc., and Manitoba Mineral Resources Ltd. Exploration uncovered a new lens and additional reserves that should be sufficient to extend the life of the mine by several years.

Chile.—CODELCO-Chile anticipated transferring the Altamira Deposit to ENAMI for public bidding and development. Altamira had ore reserves of 12 million tons grading 2% to 2.5% copper. A 4,000-ton-per-day ore processing operation was envisioned.

Papua New Guinea.—In the Papua New Guinea Highlands, work continued on testing the promising copper discovery at Wafi, 105 kilometers southwest of Lae. CRA Ltd. purchased Elders Resources' 45% equity in the project, thereby acquiring total ownership. CRA's major copper-gold mine on Bougainville remained closed, and Bougainville Copper Ltd. continued to monitor the situation closely. Until a political solution is reached and law and order reestablished, the mine will not reopen. The Wafi prospect, which was considered a major copper find, would be an open pit with byproduct gold. CRA spent \$17.6 million on exploration in 1991 and was still investigating landowner status.

U.S.S.R.—Considerable interest was generated by the potential development for a large, world-class U.S.S.R. deposit in the Chita District of Siberia. The Udokan copper deposit was reported to have reserves of 1.25 billion tons of ore, grading 1.3% copper. It was described as one of the world's largest undeveloped copper deposits. Foreign companies were being invited to bid on the development although all labor and equipment was expected to be drawn from within U.S.S.R.

Production Disruptions.—Mine closures have accounted for an estimated 563,000 tons of mine capacity lost over the period 1987-91 in Brazil, Bolivia,

Canada, Finland, Germany, Japan, Mexico, Morocco, Namibia, Norway, Peru, Papua New Guinea, Philippines, Poland, the Republic of South Africa, Spain, Sweden, the United States, Zaire, Zambia, and Zimbabwe. In addition, about 217,000 tons and almost 100,000 tons of production was lost from Zaire and Zambia, respectively, through industry deterioration. Another 187,000 tons of copper mine capacity was expected to close in 1992, including the large Tyrone Mine in the United States.

Canadian copper mine production was anticipated to decline over the near term as new capacity would be insufficient to match mine closures.³⁵ One of the main reasons is the lack of base metal exploration that prevailed during the 1970's and early 1980's. Copper production was anticipated to decline to 725,000 tons by 1997, from the current level of 800,000 tons. Although a number of new promising deposits had been discovered, lengthening lead times required were seen as delaying their entry onto the market. By the year 2000, it was forecast that Canadian production could reach current levels once again. In Quebec, copper output would decline despite the planned startup of the large Louivcourt deposit, the Ragland Mine, and Grevet Project development. By the year 2000, almost all of the Province's existing copper mines will have closed as a result of reserves exhaustion. The large Windy Craggy Project in British Columbia, because of significant environmental problems, will not begin until 1998 or later.

In Canada, several mines shut during 1991. The Afton Mine in Kamloops, BC, closed in August 1991 because of lower copper and gold prices and increased smelting and refining charges. The operation still had reserves of 18.4 million tons of 0.45% copper, enough for 7 more years. The mine was owned 73% by Teck and 23% by Metall Mining. The Opemiska underground mine in Quebec, operated by Minnova Inc., closed in June 1991 when reserves were exhausted. About 5,710 tons of copper was produced at Opemiska in 1991. Noranda's Lyon Lake Mine and the Mattabi Mine of

Ontario were both closed in early 1991 because of reserves exhaustion. In June, Breakwater Resources Ltd. suspended mining at its Estrades massive sulfide mine near Joutel owing to low metal prices. At the end of 1990, reserves at Estrades were 940,000 tons, grading 10.7% zinc, 0.94% copper, 0.92% lead, 182 grams per ton of silver, and 5.6 grams per ton of gold.

In British Columbia, closures were anticipated over the next few years at the Bell and Equity Silver Mines (1992), Samatosum Mine (1993), Island Copper Mine (1996), and Similco and Goldstream Mines (1997). The Bell copper mine was expected to shut down in mid-1992, as economic ore reserves will have been depleted by that time. Minnova's Ansil Mine was scheduled to close in early 1993 owing to reserve depletion. The Samatosum Mine, BC, owned 70% by Minnova and 30% by Rea Gold, which was started in 1989, was scheduled to close in late 1992 because of reserve depletion.

Several labor strikes, most of short duration, were to also impact production during the year. A 4 1/2-month strike severely affected copper production from Princeton Mining's properties in British Columbia, and only about 15,000 tons of copper was produced in 1991, compared with about 25,000 tons of copper in 1990. A wildcat strike by more than 500 workers at Mexicana de Cananea's mine in Mexico lasted 6 weeks in June and July. A 138-day strike at the 2,000-ton-per-year San Francisco del Oro Mine in Mexico ended with 600 workers losing jobs in cost reduction moves. The market took the 2-week strike in July at Chuquicamata, Chile, in stride. A 3-week strike at El Teniente followed in August.

In Chile, both the El Teniente and El Salvador Mines had production problems. The rockburst problem at El Teniente was restricting production and at El Salvador, reserves were limited. CODELCO-Chile was developing a new production area, El Inca, which will allow El Salvador to continue in operation for a further 15 years, but with a 10% drop in output because the new area was in harder,

primary ore. An extensive exploration program was planned between Copiapo and Taltal in hope of finding a new big deposit. CODELCO-Chile was exporting El Salvador's clean concentrates and smelting Chuquicamata's high arsenic material at Potrerillos to avoid penalties. The El Salvador mill treated ore from Quebrada M open pit and El Salvador underground mine, but because of ore shortage it also treated slag from the Chuquicamata smelter, producing about 30,000 to 35,000 tons per year of copper from this source. Oxides from Quebrada M were stockpiled for leaching, which was to begin in 1994, producing 10,000 tons per year of SX-EW cathode.

At Chuquicamata, mined ore grades had fallen from 1.64% copper in 1987 to 1.29% in 1991 and were forecast to fall to 1.00% copper by 1995. As a result of major mill expansions completed in 1989, output levels were maintained in 1990, but by 1991, output fell by about 6% to 541,600 tons of recoverable copper, partly in response to the drop in ore grades, but also because of the 2-week strike.

It was becoming apparent that the production problems in Zaire would be long term and persistent. Analysts were projecting mine production for 1992 at about 160,000 tons, less than one-half the industry's potential. Gecamines was in need of investments for modernization and repairs, and the political unrest would probably dissuade any financial interest there.

Smelting and Refining.—New Smelter Capacity.—Plans for several new greenfield smelters continued to be announced during the year, but some were not as favored as others. The list of planned new smelters or new capacity at established smelters was long and included projects in Australia, Brazil, Canada, Chile, China, Indonesia, Japan, Thailand, Pakistan, Poland, the Republic of South Africa, and the United States. World smelter capacity was estimated to total 12.5 million tons in 1991, including scrap and low-grade SX-EW capacity, but was anticipated to increase to 14.2 million tons by 1995, if the planned

projects were completed. If all were instituted as planned, about 1.7 million tons of additional capacity would be available by 1995. However, by yearend, it already was apparent that two of the planned smelters, one in Texas City, TX, and one in Portugal, were to be canceled.

The smelter constraints felt around the world were being met with creative marketing skills and partly solved by shipping to many parts of the world where there was excess capacity or negotiable smelter charges. Indonesian concentrates were going to the United States, South African concentrates to Poland, Canadian concentrates to Mexico, and some concentrates to the excess capacity in the Commonwealth of Independent States (C.I.S.), and so forth. Combined TC/RC had escalated and by yearend, were 47% higher than at yearend 1990. The higher smelter charges were a major factor in causing some smaller mines to close. The combination of higher processing charges and good copper prices was promoting some concentrates to be transported to remote smelters around the world such as to the C.I.S., Poland, and Zambia.

The Southern Copper Co. refinery and smelter at Port Kembla, New South Wales, was established as a separate business unit in 1991. The major renovation to the smelter was completed by March 1991 with commissioning of the Noranda flash furnace, the acid plant, and new converters. The new anode furnaces and rotary anode casting wheel were completed in September. About 25% of the smelter's feed is scrap, and up to 50% of the smelter needs will be imported. Requirements were for 250,000 tons per year of concentrates. The smelter was treating Woodlawn Mine, Australia, and Burma and Turkey concentrates. The tankhouse equipment was also modified, solving some problems, but production at the tankhouse was lagging during its rebuilding program.

Australia's MIM planned to install a new Isasmelt furnace at Mount Isa that will increase smelting capacity from the current 180,000 tons per year to about

210,000 tons per year. The plant would be commissioned in the second half of 1992. The plant would have potential for 250,000 tons per year depending on availability of concentrates for feed. Some concentrate would have to be purchased from overseas. The refinery at Townsville had raised capacity to 200,000 tons per year.

In August 1991, Minorco bought Hudson Bay Mining and Smelting from its 56.2% subsidiary Inspiration Resources for \$85 million. Hudson Bay planned a \$156 million modernization program of the 70,000-ton-per-year Flin Flon smelter to modify it to meet emission regulations. The existing smelter had no acid plant and had until 1994 to comply. The new smelter, which will use Noranda reactor technology, was scheduled for startup in mid-1993 and will run along with the old plant until 1994. Smelter capacity will increase to 80,000 tons per year of copper, an increase of about 10,000 tons.

Inco planned to invest \$357 million in a new 600,000-ton-per-year sulfuric acid plant at its Copper Cliff smelter. At the same time, the smelter would be modified to treat concentrate in two new Inco flash furnaces, with the original reverberatory and flash furnaces being shut down. The first of the new furnaces was commissioned in October 1991, and the second was to be completed by 1993. The smelter capacity would remain at 130,000 tons per year. There is also an electrowinning circuit to recover 10,000 tons per year of copper from nickel refinery liquors. In 1991, Copper Cliff began processing matte from the new Radio Hill smelter in Australia.

In 1992, PRM Resources Ltd. planned to undertake a full feasibility study for its copper smelter/refinery project at Kitimat, BC. The \$500 million facility, which would have a 200,000-ton-per-year copper capacity, would process both Canadian and imported concentrates. Most British Columbia concentrates were exported to Japan.

An expansion at the Ventanas smelter in Chile was to increase throughput by 300,000 tons per year to 800,000 tons per year of concentrates, replace the

reverberatory furnaces with flash smelting technology, and add an acid plant. The renovations were estimated to cost about \$250 million. The smelter's current capacity is about 500,000 tons per year of concentrates. The Ventanas expansion was linked with CODELCO-Chile's plans to increase Andina Mine's production from about 115,000 tons per year to almost 200,000 tons per year of copper at a cost of about \$240 million. Andina's concentrates were exported, but would be treated at Las Ventanas following the expansion.

Exxon Corp.'s Chilean unit, Cia. Minera Disputada Las Condes, was trebling its smelting capacity at Chagres to almost 125,000 tons of blister copper per year. Cia. Minera Disputada will replace the 44,000-ton-per-year reverberatory furnace at Chagres with a new Outokumpu flash furnace, increasing capacity to 120,000 tons by 1993 and 160,000 tons by 1997. The expansion will allow the Chagres plant to be the first smelter in Chile to cogenerate electric power. The older smelter was closing 30 days per year to cut back on pollution. Disputada also was considering investing in a refinery to match smelter capacity at its expanded Chagres smelter.

At Caletones, Chile, smelter expansion plans included a new furnace and at the Potrerillos smelter, a reverberatory furnace would be replaced by an El Teniente modified converter. Acid plants were to be built at each. The smelters serve the El Teniente and Salvador Mines. Each project would increase capacity by 200,000 tons per year of concentrates. However,

CODELCO-Chile reportedly could not afford to go forward with these renovations simultaneously with others planned, so no firm schedule was given for completion of these projects. Among CODELCO-Chile project priorities was the projected investment of \$66 million to add smelting capacity at Chuquicamata by 1994. Modifications to the El Teniente converter and a new oxygen plant were planned to increase capacity to 525,000 tons per year of blister by mid-1992. Chuquicamata's two remaining

reverberatory furnaces may also be replaced with a flash furnace, but these plans were not firm.

Davy McKee was conducting a \$580,000 feasibility study for a new greenfield smelting and refining complex in Chile. The Refineria del Pacifico smelter would treat about 800,000 tons per year of concentrates, producing about 220,000 tons per year of copper in blister. The investment required was anticipated to be about \$450 million. The study was commissioned by ENAMI along with Lac Mineral Inc., ACEC-Union Miniere, ARBI Participacoes-Caraiba Metais, and Sudamericana de Metales. If successful, Lac Minerals planned to supply the new smelter with about 70,000 tons per year of concentrates from the El Indio Mine.

China National Nonferrous Metals Import and Export Corp. (CNIEC) expanded the Bayin smelter and refinery in early 1991 from 40,000 tons to 110,000 tons per year of copper. CNIEC was planning an expansion to the copper smelter at Daye in southwest China. Currently operating with a capacity of 220,000 tons per year of concentrates (30,000 tons per year copper), a new Noranda reactor will be installed (410,000 tons per year concentrates) by Noranda Copper Smelting and Refining. The new smelter would be operational in late 1994. The new capacity would be about 110,000 tons per year copper in blister. China also announced the construction of a \$120 million, 60,000-ton-per-year copper smelter in Tianjin, 200 kilometers southeast of Beijing. The plant was expected to start in 1995.

Hindustan Copper's Khetri, Rajasthan, smelter was being expanded from 31,000 tons per year of copper to 45,000 tons per year over the next 2 years. The company hoped to supply about 70% of India's copper needs by mid-1990.

The Indonesian company PT Petrokimia Gresik and Freeport Indonesia Inc. announced plans for the construction of a \$580 million copper smelter in Gresik, East Java, Indonesia. A 150,000-ton-per-year copper smelter was planned.

Outokumpu was planning an upgrade of its Harjavalta smelter, Finland, to

about 200,000 tons per year. A feasibility study was under way, and the upgrade was expected to cost about \$180 million.

Mitsubishi Materials Corp. started operation of its continuous smelting and refining furnace in October 1991 at Naoshima Works, Kagawa Prefect. The smelting capacity was 20,000 tons of concentrate per month, including 3,000 tons of copper anode from scrap.

A furnace rebuild project was completed at Mexicana de Cobre's La Caridad smelter in 1991. Improved processing efficiencies were to allow greater smelter output from the 170,000-ton-per-year smelter. Imports of concentrates from Canada have also contributed to higher output at the La Caridad Smelter during the year.

In the Republic of South Africa, a \$23 million smelter upgrade project at Palabora was expected to increase the company's refined copper production by 5% when it was completed in 1992.

In Thailand, Rayong Copper Industry (RCI), a joint venture led by Padaeng Industry Co. (PDI), was hoping to start construction of a 150,000-ton-per-year copper smelter and refinery project by the end of 1992. RCI was composed of PDI (51%), Mitsubishi Materials (13%), MIM (12%), Marc Rich (9%), and Mitsubishi Corp. and Mitsui Corp. (7.5% each). Bechtel International was providing technical consultancy, and Citibank was reportedly securing funds for the \$345 million project. Production at the plant was planned for 1995.

At present, Thailand does not exploit its copper reserves, estimated at more than 97 million tons, found in the northeastern Provinces of Loei and Nong Khai. However, the PDI also planned to build a \$61 million copper smelter at Rayong on the coast east of Bangkok with a 15,000-ton-per-year capacity. The plant was planned for a startup at the end of 1992 at 60% of capacity, reaching full capacity by 1995.

In Zambia, major smelter modernization projects were underway at Nkana and Mufulira. At Nkana, one of the reverberatory furnaces was converted to oxy-fuel firing and an El Teniente

Modified Converter (TMC) was to be installed in 1992, together with new gas-handling equipment and revamping of the acid plants. At Mufulira, the electric furnace was being rebuilt. CODELCO-Chile was providing the engineering services and Techpro Mining and Metallurgy was to complete the detailed design. The gas-handling equipment was inadequate and needed major modification before full benefits of additional equipment can be gained. These conversions will permit a production rate of 240,000 tons per year of copper with only three reverberatory furnaces (one oxy-fuel and two conventional fuel-air burners) and three converters (the TMC and two Peirce-Smith). Energy consumption should also fall to about 4,200 megajoules per metric ton and decrease operating and maintenance costs. With higher sulfur dioxide in the off gases, production of sulfuric acid should increase, especially with acid plant repair.

Smelter Production Disruptions.—Smelter production was disrupted as a result of regular maintenance procedures, accidents, startup difficulties, or environmental considerations in Australia, Canada, Chile, Zambia, and the United States. The Miami, AZ, smelter in the United States was down for an extended period late in 1991 owing to a fire. In Australia, technical difficulties disrupted the Southern Copper smelter startup, and in August, an explosion inside the furnace caused significant damage. Repairs and restoration took 39 days, but furnace operations resumed normally thereafter by the first week in October. It was estimated that it might be up to 12 months before the smelter could reach rated capacity of 80,000 tons per year of copper, however.

Delays in the rebuilding of ZCCM's Mufulira smelter in Zambia resulted in a build up of 70,000 tons of copper concentrates by yearend 1991. Increased production at the Nkana smelter and the restart of the Luanshya plant were unable to cope with the concentrate stockpile.

Refinery Production.—World refinery production was almost 10 million tons in 1991, but represented a decrease of 5.5% over that of 1990, largely as a result of the smelter bottleneck, but also because of problems in Zairian blister delivery. Both the United States and Chile increased SX-EW capacity. SX-EW capacity was 1.074 million tons in 1991, about the same as that in 1990, but was expected to increase to 1.6 million tons by 1995. About 600,000 tons of new greenfield refinery capacity was planned by 1995 in projects announced for Brazil, Canada, Chile, China, Peru, Portugal, and Thailand.

Nearly three-quarters of Australia's mine output was refined domestically. Anode and blister was produced at Mount Isa and cathode copper refined at the company's Copper Refineries Ltd. (CRL) plant in Townsville, the largest refinery in Australia. Both the Southern Copper smelter at Port Kembla and the Roxby Downs smelter have associated refineries. A small amount of copper also was produced by Pasminco's BHAS smelter in Port Pirie as a byproduct. All three refineries were upgraded or were in the process of being upgraded. Southern Copper was planning to double refinery capacity to 80,000 tons per year of copper by the middle of 1992. Capacity also was anticipated to increase to 66,000 tons per year at the Olympic Dam Refinery. Currently, more than 80% of the Roxby Downs smelter output was exported. By the beginning of 1993, Australia's refinery production was planned for increase by an additional 90,000 tons per year from the current level of about 350,000 tons per year.

In Bulgaria, a new tankhouse was to be completed at the Georgi Damyanov refinery at Srednogorie by 1993. The capacity of the tankhouse would be raised to 120,000 tons per year of refined copper.

A new copper refinery, Cobre de Pasteje, started operation in Mexico during the year. In response to the environmental problems of Mexico City, the electrolytic refinery of Cobre de Mexico was transferring some of its

production to its new facility in Celaya, Guanajuato.

Southern Peru Copper Corp. (SPCC) and Minero Peru were considering joint operation of the Ilo refinery. The 175,000-ton-per-year copper plant was owned by Minero Peru. A 7,000-ton-per-year expansion at the Ilo refinery resulted from more efficient use of electricity and was completed by the end of the first quarter 1992.

Poland produced 376,800 tons of refined copper in 1991, up about 10% from that of 1990. Custom smelting of imported concentrates from the Republic of South Africa comprised about 35,500 tons. About 70% of production was exported by Kombinat Gorniczno-Hutniczy Miedzi (KGHM), the Government-owned copper company. Production cash costs for 1991 were reported to be about 67 cents per pound after a 13-cent-per-pound silver byproduct credit. Owing to increased power prices, however, production costs were expected to be higher in 1992, perhaps as high as 80 cents per pound. The main thrust for the future was to be the modernization of facilities and the reduction of costs. Both Western Mining Corp. and Asarco offered to help KGHM in a modernization program. One major social problem that may have to be faced would be the significant reduction in the 40,000-strong work force that could result in major unemployment. A proposal was under consideration to form four copper companies, one for mining, a semifabricating company, an engineering and construction company, and a company to handle transport of copper materials.

Capacity.—Compared with that of 1990, world mine capacity increased by 2.1%, smelter capacity by 1.1%, and refinery capacity by less than 1%. Copper mine, smelter, and refinery capacity for 1991 is shown in table 8. World capacity utilization (82%) at mines was very low in 1991 owing to continued production disruptions, discussed in the previous section. The capacity utilization rate would have been lower except for the significant reduction

in Zairian capacity to bring it more into line with current potential. Since 1974, average annual world mine production has ranged between 79% and 85% of available capacity, being highest during periods of peak demand and low available capacity, such as existed in 1987, a year of high capacity (85%) utilization. (See table 8.)

The data in table 8 are rated annual production capacity for mines, smelters, and refineries as of December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgement of the author, can be brought into production within a short period of time with minimum capital expenditure.

Capacity at mines represents the potential copper production contained in concentrates for many producers, but for some major producers—such as Chile, the United States, and Zambia—it represents copper recoverable at the smelter level, based on known recovery factors. SX-EW capacity is counted as smelter-level capacity only when the material must be further refined. It is otherwise counted as mine and refinery capacity, bypassing the smelter level. Past and present production potential are taken into consideration when rating a mine, especially where an engineering estimation is not available or seems inappropriate in the case of decreased ore grades. Generally, the rated capacity is based on 360 days per year and 2 to 3 shifts per day. For new facilities, capacity is prorated for the year in which it started, but the full capacity is used for the year in which a facility closes. Mines and plants generally are not counted if they are not operating at any time during the year, except where it may be reasonably expected that a shutdown may be temporary; i.e., usually less than 2 years. The closed mine at Bougainville, Papua New Guinea, was not counted as

available capacity during the year because its closure has exceeded 2 years. The cost to reactivate this mine was considered almost that of a new mine, and so it clearly falls into the long-term closure category.

Reserves and Resources.—The definitions for reserves and reserve base are published in U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals." In this system, the reserve base is the measured plus indicated (demonstrated) resource from which reserves are estimated. Reserves are that part of the reserve base thought to be economically recoverable with existing technology at operating or developing properties. Among individual countries, Chile (24%) has the largest share of the reserve base, followed by the United States (15%), the U.S.S.R. (9%), and Australia (7.3%). Indonesia, Peru, Zaire, and Zambia also have large copper reserves. (See table 9.)

More than 90% of U.S. copper reserves was in five States—Arizona, Michigan, Montana, New Mexico, and Utah. The U.S. Geological Survey estimated that total world land-based copper resources, composed of the reserve base and a larger body of less well-characterized resource, was about 1.6 billion tons.

Copper reserves reported at operating or developing properties were sufficient to meet a projected cumulative demand of almost 118 million tons of primary copper through the year 2000. In addition, some of the material already identified in the reserve base, which was presumed to be uneconomic to mine, may become economic with new technology and/or higher copper prices. However, the rate of increase in the reserve base has declined since 1976. The world reserve base, including measured and indicated ore, increased by about 140% from 1965 to 1976, corresponding to a 56% growth in world production and 48% growth in consumption over the same period. Since 1976, however, the reserve base has increased by only 28% and production by only 21%, while

consumption grew by an impressive 36%. Since the late 1970's, the preoccupation with gold exploration and general neglect of base metal exploration led to a significant decline of reserves in Canada, Peru, the Philippines, and other countries. U.S. reserves have remained more or less static. Unless substantial new discoveries are made immediately, some countries' output will decline by the late 1990's.

OUTLOOK

Trends in Consumption

While reported refined copper consumption in the United States was down by about 4.3%, MEC consumption increased by 1.42% in 1991. This was a result of continued strong growth in several Asian countries. The European countries also indicated a lackluster copper consumption growth. Taking a longer view between 1980 and 1990, international demand for copper has been very strong, with copper demand in the MEC rising at an annual average of 1.7%. Copper demand growth for the 1980-91 period was about the same as for those of other nonferrous metals, such as aluminum and zinc, each of which rose by 1.6% per year. Higher rates of economic and investment growth in the 1980's compared with the 1970's prompted increased metal usage. A slowdown in substitution rate also favored copper.

The information technology revolution in the past 10 years caused rapid computerization of U.S. industry, together with increased electrical requirements in homes and vehicles. There also was a move back to copper plumbing in both housing and industrial building. Building wire use in single family homes in the United States was up by 20% in the past 10 years. The key factor for copper consumption growth was the need for new metals-intensive industrial investment, plus the competitive strength of copper to other materials.

Historically, world demand has risen steadily with only an occasional setback owing to economic recession, a trend that

was expected to continue. The importance of copper demand growth as it relates to the modern society may be observed by comparing trends with the world's population growth. As shown in figure 12, U.S. per capita copper consumption since 1950, while irregular owing to recessions and other economic phenomena, has averaged 20 pounds per person per year. The flattening of the U.S. curve in the past 10 years was largely owing to decreased market share by domestic mills owing to increased competition from foreign imports. By contrast, global per capita use of copper, which includes copper consumption in all economic sectors, has exhibited a steady increase averaging 1.66% per year between 1950 and 1990. If this long-term growth trend in copper demand per person continues, population pressure alone could result in requirements for about 15.7 million tons of copper in the year of 2000, significantly above our current forecast. In recent years, the per capita demand growth has slowed and, thus, demand in the year 2000 might be expected to be somewhat lower than the long-term trend would indicate, should these lower economic growth rates prevail for the world. However, the noticeable gap between the average annual 4.7 pounds per person consumed for the world and 20 pounds per person in the United States illustrates the considerable growth potential needed for an equivalent living standard. (See figure 12.)

Copper consumption growth in the Asian countries continued to add to increased world consumption, despite the economic malaise in the United States and Europe. In 1991, the Chinese economy reportedly grew by an impressive 10% and was a significant importer of copper. Consumption spending may be expected to continue to increase as a result of rising incomes and the continued investment in infrastructure development. Some analysts were predicting that China's demand will rise to 810,000 tons in 1992, from the 650,000 tons of 1991. As a result, imports of copper to China will continue to be an important feature of its economy

because it will need in excess of 200,000 tons to cover the supply shortage. Development of China's infrastructure was crucial to its economic growth. Telecommunications and transportation were both priority areas in China's eighth 5-year plan. Chinese refined copper consumption may reach 780,000 tons in 1993, about 30% over that of 1991. Some C.I.S. copper mine production was slated to be shipped from the C.I.S. to smelters in China. Growth trends in other Asian countries, such as Taiwan, Korea, and Japan, were anticipated to be lower over the next 3 years, supported by a more modest economic growth. India's need for copper has grown much more rapidly than its production of the metal and the country was dependent on imports for about 70% of its needs. Consuming about 135,000 tons of copper in 1990, India's consumption was expected to grow to about 292,000 tons by the year 2000. Several new rod mills have been constructed within the past several years.³⁶

Trends in Supply

On the supply side, the inventory of base metal reserves developed in the early 1980's has been drawn down. Political unrest in Papua New Guinea, Zaire, and Zambia has sharply curtailed copper supplies in these areas. It is difficult to determine how much capacity in the former communist countries will survive the rigors of market-based economies. There may actually be a decline in production from inefficient and environmentally dangerous operations that are shut down.

The conflict continued between mining and environmental forces. In Wisconsin, new mining legislation and a stringent permitting process have caused development delays for new discoveries. The uncertain status of Windy Craggy and Eskay Creek and cancellation of the Mount Milligan deposit development may discourage new exploration in that area.

As environmental requirements become more stringent in the industrialized nations and the mine-producer nations strive to develop their manufacturing

industries, there will be an increased move toward building new smelters and refineries nearer to the mine source in these and other nations, where it is affordable, and the process of permitting is quicker and easier. An example of a failed attempt to establish a new greenfield smelter in the United States was the Mitsubishi Corp. Texas City, TX, smelter project, which finally was withdrawn because of stringent water permit requirements that demanded zero discharge. About \$10 million and almost 3 years was spent in the attempt to start the project.

Three major copper projects were stalled in British Columbia, Canada—Mount Milligan, Windy Craggy, and Mount Polley—waiting for Mine Development Certificates (MDC). The MDC was issued only after review of environmental and socio-economic studies completed by the applicant. Complicating the problem was the increased involvement of the Canadian Federal Government and the full-scale Federal environmental assessment. The Mining Association of British Columbia identified more than 40 Federal statutes that could trigger an environmental assessment. Companies must wait until the regulatory requirements are finished before proceeding with construction financing. Projects were becoming more and more expensive before this happened, meaning millions of dollars was spent without knowing whether the deposit would ever go into production.³⁷ By yearend, the Mount Milligan project was canceled by Placer Dome. The Windy Craggy debate had become more of a land-use issue than an environmental concern.

According to one report,³⁸ investment in new mining projects suffered a sharp decline in 1991, as lower metal prices limited access to capital. There was a 21% dropoff in new projects reported to the 1992 Engineering and Mining Journal Project Survey, and more than a 22% decrease in the total dollar value of those projects. South America once again attracted most of the investment capital, but most of the projects were reported in North America. The nature and perception of mine project risk has

changed significantly in the past 20 years as fears of nationalization or expropriation have receded. The destabilizing effects of high oil prices of 10 to 15 years ago have disappeared along with the retreat of the petroleum companies from the mining industry. The basic structural imbalances caused during this era have largely been corrected. However, the problems of unstable governments continue, as do the new concerns related to land-use planning, the environment, AIDS, and social responsibilities. Bank financing tightened in the wake of the U.S. Savings and Loan crisis and its strain on bank liquidity. The collapse of real estate markets in the United States was also putting a strain on other sources of funds, such as insurance companies. These traditional sources of funds were becoming increasingly conservative in their lending practices. The high less developed country (LDC) debts incurred during the 1970's and 1980's and their defaults were also having an effect on the ease of lending.

Forecast Supply and Demand Trends

The copper market will remain stable in 1992, with significant U.S. consumption improvements and strong demand from China. It is estimated that Western World consumption will grow by 3.35% per year, increasing to 14.1 million tons by the year 2005 (see table 10). World copper consumption may grow as much as 3.46% per year to about 14.6 million tons by the year 2000. U.S. consumption had grown at an average rate of 1.34% per year between 1950 and 1988, as indicated in figure 13, and though it has been below this rate since 1989, it was anticipated that this trend will be regained as recovery from the current recession proceeds. (See table 10 and figure 13.)

Supply and demand are projected to remain relatively balanced during the early 1990's as a result of stable copper consumption growth and continued smelter bottlenecks. Copper inventories may rise modestly because of increased mine production. The possibility of

continued supply disruptions remains a concern. Higher rates of domestic consumption in the Far East, Central and South America, and a unified Germany should continue over the near term. Another positive factor for higher consumption rates will be a higher intensity of use in building and automotive sectors. The potential for infrastructure improvements in Eastern Europe and the Far East later in the decade will also help to maintain a balance between supply and demand.

A fairly optimistic view of copper consumption for the MEC was based in large part on the anticipation that LDC's will enjoy a faster economic growth in the early 1990's than in the late 1980's as the Latin American countries join developing Far Eastern countries in industrialization and higher copper consumption. In addition to a buoyant LDC consumption, the robust performance of copper is anticipated as a result of the failure of optical fiber to attain the complete substitution in the telecommunications end-use sector that many had anticipated. While some applications, such as long-distance networks, for example, have demonstrated the usefulness of optical fibers, this accounted for only a very small proportion of the copper used in the telephone system. According to some sources, optical fiber networks have proven to be a net plus for copper because more was being consumed in devices at either end of the fiber link than is displaced by the cable itself. Aluminum's inroads into copper cable areas also was not growing as rapidly as was once the case, and copper was retaking some of the market for replacement automobile radiators. Demand for sophisticated new automotive systems will require additional wire manufactured from copper. In the United States, the resurgence of electric cars is being prompted by tough air quality regulations. Several U.S., European, and Japanese automakers are updating their electric-car technology.

Copper demand from new housing starts in the United States was expected to increase by 27% in 1992, compared with

that of 1991.³⁹ After reaching a peak in 1986, housing starts have been in decline every year, so 1992 would represent a reversal of the 5-year trend. The National Association of Home Builders' (NAHB) 1992-93 forecast called for total housing starts to reach 1.28 million in 1992, of which 1.08 million are single-family units. In 1991, housing starts totaled 1.01 million with 840,000 single-family units. This translated into 240,268 tons of copper for housing in 1992, up from 189,194 tons achieved in 1991. The additional 240,000 single-family units represent 47,809 tons of copper, based on CDA's average of 439 pounds per 2,100-square-foot dwelling. The 26,000 new multifamily units equate to 3,266 tons of copper, based on CDA's average of 278 pounds per 1,000-square-foot unit. Momentum was forecast to continue into 1993 with an 11.3% increase in total housing starts over 1992.

For the mid-1990's, expect growth in consumption, balance between supply and demand, and relatively stable prices. World economic activity will improve copper consumption by the second half of 1992 and continue into 1993. Western World consumption will increase about 4% in 1992. Production will be limited by smelter capacity, which will affect refined production. A modest surplus of about 200,000 tons is anticipated for the Western World in 1992. Consumption will grow in the range of 1.7% to 4.7% through the 1990's. Strongest growth will be in the Far East. Asia's share of market economy consumption will increase from 32% to 34% in the next 10 years. Korea, Malaysia, Singapore, Taiwan, and Thailand will equal that of Japan. By 1995, domestic demand for copper in Thailand is projected to increase from 75,000 tons to 100,000 tons per year. Latin America will also improve, as well as Eastern Europe and China.

The decline of communism changed political agendas of western democracies, and government expenditures shifted from defense to infrastructure rebuilding. The former communist countries also must increase capital spending to modernize

and improve infrastructure. Increased copper will be needed for infrastructure and industrialization. While production and consumption rates for the former U.S.S.R. were anticipated to be lower over the short term, these should be measurably higher by 1996 as western investments and market practices start to take hold. At the same time, some processing plants such as smelters and refineries may have to be closed because of environmental concerns and costs. Some reports anticipate refinery capacity to be reduced by as much as 500,000 tons by 1996. In Eastern Europe, the development and improvement of telecommunications, building construction, and electricity in these nations will require considerable copper. There was a desperate demand for housing in the C.I.S.

One factor that was expected to continue to hold down the increase in mine production over the next 5 to 10 years was the plight of the African nations Zaire and Zambia. Both countries were expected to be producing less copper, although some recovery might be anticipated by 1995. Zambia's new Government offered some hope for improvement, but only a major investment of foreign capital would reverse the downward trend. The same can be said for Zaire, but restoration to the previous 500,000-ton-per-year level was seen as unlikely because of the current political situation. Expatriates working on the mines left, aid donors suspended their programs, and there was an AIDS epidemic in this part of the world that was likely to take a long-term toll on the economies of these countries.

Forecast trends for mine capacity at mines currently operating, developing, or closed in 1991 are shown in table 11. Most operating mines will experience a drop in copper production by the year 2000. Capacity at operating mines was forecast to decrease by almost 6% in the United States by the year 2000. Mine capacity growth in Chile on the other hand can be expected to be robust with copper output rising by 36% over the 1991-96 period to a 2.7-million-ton-per-year level and to over 3 million

tons per year by the year 2000. The United States also has the potential to increase mine capacity to about 2.5 million tons per year by the year 2000, but the increases will have to come from projects currently in exploration and development phases. The projected increases were very speculative and subject to delays by environmental requirements. Indonesia and Australia also were seen as attaining major increases in their mine output over the forecast period. More than 34% of future copper mine capacity will have to come from mines currently closed or in exploration and development, as only 66% of capacity in the year 2005 will be available from mines currently operating, as shown in figure 14. If current demand forecasts are nearly correct, this capacity will be insufficient. Not only are there many doubts about the ability of the industry to develop these speculative new mines, but additional new projects will be needed, as yet undiscovered. (See table 11 and figure 14.)

Despite the money tightness, top-tier mining companies that meet all the financial criteria of a good balance sheet and a low-production-cost project should have little trouble finding outside capital. To obtain easy financing for a copper project, cash production costs of about 60 cents per pound were indicated.⁴⁰ There was considerable concern, however, that many of the world's mining projects may not find suitable financing in a timely manner, as easily as they have in the past. To attract new private-sector capital investments, Governments need to identify and implement measures to reduce risks for investors and lenders considering exploration and mine development. Exploration, mining, export, and employment rights were all areas of risk and concern, in addition to good taxation and foreign exchange provisions. Obtaining capital for new mining investments may be a problem not only for countries such as Zambia and Zaire, which were struggling with internal problems, but also for countries such as the United States and Canada, which were struggling with diverse

interests that were opposed to development.

Some analysts observed that there was a marked decrease in exploration interest in the United States and Canada as companies joined the rush to seek out opportunities in less hostile ground in Chile and Mexico. With the spirit and intent of the 1872 Mining Law of the United States under attack, and increased withdrawal of public lands for exploration, the existing legal, financial, and environmental climate was squeezing out prospectors and mining companies that had typically generated new projects of the past. Canadian and U.S. companies were paying considerably less attention than they did some years ago to acquiring reserves in North America. Other South American countries were offering projects, including Argentina, which was putting up about 15 projects for bidding. Although the geological potential was good in Africa, these were still considered risky because of continued political uncertainty, high costs, massive bureaucracy, and health concerns. Mining opportunities in the C.I.S. also were popular, but carried some risk while the people adapted to a changing political and economic climate. Exploration expenditures in British Columbia were down roughly 50% from those of 1990, according to some analysts.

A comparison of supply and demand balances over the 1974-2005 period may be illustrated by comparing actual and projected inventory trends, as shown in figure 15. The trend line for 4 weeks of MEC copper consumption highlights the potential shortage that is forecast for the mid-1990's. Previously forecast surpluses for the 1991-95 period do not seem to be materializing, owing to substantial supply disruptions over the past 3 years. The slowdown in copper consumption that coincided with these disruptions over the past 2 years has not been severe enough to compensate for the supply deficit. As a result, the balance between supply and demand has remained relatively tight. (See figure 15.)

¹All quantities in this chapter are given in metric tons unless otherwise specified.

²World Bureau of Metal Statistics. World Metal Statistics. June 1992. Hertfordshire, United Kingdom. p.38.

³Page 39 of work cited in footnote 2.

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⁵Lechtman, H. Pre-Columbian Surface Metallurgy. Scientific Am., Spring issue, 1984, pp. 56-63.

⁶Reyna, G. Riqueza Mineral Y Yacimientos Minerales de Mexico. Monografia Industriales del Banco de Mexico, S.A., 1947, pp. 173-183.

⁷Benavides, A. Q. Exploration and Mining Ventures in Peru. Econ. Geol. Bull., V. 85, pp. 1296-1302.

⁸Northern Miner. The Caribbean Island Arc--A Major Storehouse. V. 61, No. 27, Sept. 18, 1975, pp. 52-63.

⁹Skilling Mining Review. State of the Mineral Exploration Industry. Oct. 29, 1984, pp. 6-8.

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¹¹Mining Engineering. RTZ Reports Progress at Several Mines and Developing Projects. June 1992, p. 525.

¹²Mackey, P. J. Trends in Copper Processing. Noranda Technology Centre. Paper in Metals Week Copper Conf., Orlando, FL (Jan. 7-8, 1991), unpublished, p. 21.

¹³Metal Bulletin Monthly. Copper and the LME. May 1992, p. 19.

¹⁴Porter, K. E., and P. R. Thomas. International Competitiveness of U.S. Copper Production 1981-1987. BuMines Mineral Issues, 1989, pp. 8-22.

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¹⁶Helmer, E. D. The Clean Water Act; Its Effect on a Copper Producer, Magma Copper Co., San Manuel, AZ, 7 pp.

¹⁷U.S. Department of Energy. Assessment of Energy Requirements in Proven and New Copper Processes. Final Report (U.S. Dep. Energy contract DE-AS07-78CS40132). Dec. 1980, 361 pp.

¹⁸Work cited in footnote 17.

¹⁹Federal Register. Environmental Protection Agency. Final Regulatory Determination for Special Wastes From Mineral Processing (Mining Waste Exclusion). V. 56, No. 114, June 13, 1991, pp. 27300-27330.

²⁰Environmental Protection Agency Final Rule on Drinking Water Regulations, July 15, 1991.

²¹ASARCO Incorporated. 1991 Company Annual Report.

²²Cyprus Minerals Co. 1991 Company Annual Report.

²³Magma Copper Co. 1991 Company Annual Report.

²⁴Phelps Dodge Corp. 1991 Company Annual Report.

²⁵Mining Engineering. Copper Mining Has Major Impact on Arizona's Economy. May 1992, pp. 410.

²⁶Work cited in footnote 22.

²⁷Work cited in footnote 23.

²⁸Work cited in footnote 23.

²⁹American Metal Market. Metal Powders. V. 99, Nos. 13 and 139, Jan. 21, 1991, and July 23, 1991, p. 20 and p. 16.

³⁰Red Metal Demand Shoots Up. V. 99, No. 25, Feb. 7, 1991, pp. a and 4.

³¹More Housing Starts Seen Hiking Demand for Copper 27% in '92. V. 100, No. 113, June 11, 1992, p. 5.

³²Nuckles. Copper Industry Stronger Than Many Might Expect. AT&T Network Network Systems. 1992 Special Supplement to Outside Plant, pp. 1-5.

³³American Metal Market. Metals, Environment Council Created by 14 Mining Firms. V. 99, No. 68, Apr. 10, 1991, p. 13.

³⁴Mining Engineering. Exploration 1991. May 1992, p. 425.

³⁵Bokovay, G. Copper. Extract From 1991 Canadian Minerals Yearbook. 1992, p. 19.1.

³⁶Metal Bulletin Monthly. Copper Rod Casters Add Value to Imports. V. 253, Jan. 1992, pp. 51-53.

³⁷Canadian Mining Journal. Holding Pattern. New Mines Wait and Wait for Okay To Proceed. Feb. 1992, pp. 10-14.

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³⁹Work cited in footnote 31.

⁴⁰Work cited in footnote 38.

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TABLE 1
SALIENT COPPER STATISTICS

(Metric tons unless otherwise specified)

	1987	1988	1989	1990	1991	
United States:						
Ore produced	thousand metric tons	202,632	223,576	237,301	*249,500	276,891
Average yield of copper	percent	0.57	0.60	0.61	0.62	0.57
Primary (new) copper produced:						
From domestic ores, as reported by:						
Mines		1,243,596	1,416,928	1,497,818	*1,587,742	1,631,078
Value	millions	\$2,262	\$3,764	\$4,324	*\$4,311	\$3,931
Percent of world total		15	17	17	18	18
Smelters ¹		972,141	1,042,961	1,120,445	*1,158,462	1,122,926
Refineries		*1,126,908	1,282,370	*1,351,747	1,502,014	1,500,544
From foreign ores, matte, etc., as reported by refineries	W		123,650	125,085	74,620	76,889
Total new refined, domestic and foreign		1,126,908	1,406,020	*1,476,832	*1,576,63	1,577,433
Refined copper from scrap (new and old)		414,738	446,427	480,018	440,757	417,761
Secondary copper recovered from old scrap only		497,937	518,179	547,561	*535,656	533,338
Exports:						
Refined		9,197	58,325	130,189	211,164	263,201
Unmanufactured ⁴		387,000	557,000	725,000	780,000	802,000
Imports for consumption:						
Refined		469,159	331,671	300,110	261,672	288,586
Unmanufactured ⁴		568,441	513,038	515,000	512,000	512,000
Stocks, Dec. 31: Total industry and COMEX:						
Refined		*112,927	*96,704	*106,656	*101,274	132,049
Blister and materials in solution		*149,694	*121,442	*131,650	*118,924	135,099
Consumption:						
Refined copper (reported)		2,127,178	2,210,424	2,203,116	2,150,426	2,048,323
Apparent consumption, primary and old copper (old scrap only)		2,196,540	2,213,768	*2,184,534	*2,168,179	2,104,968
Price: Weighted average, cathode, cents per pound, producers		82.50	120.51	130.95	123.16	109.33
World:						
Production:						
Mine	thousand metric tons	*8,243	*8,323	*8,667	*8,693	8,820
Smelter	do.	*8,937	*9,191	*9,413	*9,087	9,052
Refineries	do.	*9,727	*10,219	*10,543	*10,546	9,961
Price: London, Grade A, average cents per pound ⁵		80.88	117.92	128.91	121.02	106.21

*Revised. W Withheld to avoid disclosing company proprietary data.

¹Includes copper content of blister and anodes produced from foreign ores and concentrates.

²Includes primary copper produced from foreign ores, matte, etc., to avoid disclosing company proprietary data.

³Data do not add to total shown because of independent rounding.

⁴Includes copper content of alloy scrap. Copper content of alloy scrap imported and exported in 1989, 1990, and 1991 was estimated from gross weight.

⁵High-grade prior to 1988.

**TABLE 2
COPPER ELECTROWON AT U.S.
MINES**

(Metric tons)

Year	Mine production
1971	32,700
1972	28,467
1973	37,068
1974	31,196
1975	36,416
1976	78,206
1977	103,652
1978	95,028
1979	97,248
1980	116,053
1981	159,029
1982	130,417
1983	101,936
1984	100,180
1985	90,438
1986	125,359
1987	161,287
1988	227,992
1989	311,885
1990	393,463
1991	441,241

Source: U.S. Bureau of Mines, July 1992.

TABLE 3
U.S. REFINED COPPER INVENTORIES, END OF YEAR¹

(Thousand metric tons)

Year	Consumers			Producers ³	COMEX ⁴	Total industry	U.S. Government ⁵	Total United States
	Brass mills	Wire mills	Other ²					
1955	39	20	4	31	0.32	93	802	895
1956	46	36	9	71	.80	163	845	1,009
1957	46	48	3	99	.70	196	918	1,113
1958	47	34	8	44	10	142	1,031	1,172
1959	30	16	11	16	12	85	1,035	1,120
1960	29	32	4	89	2	157	1,040	1,197
1961	34	26	8	44	8	120	1,036	1,156
1962	31	34	6	64	4	139	1,029	1,168
1963	30	15	4	47	1	97	1,018	1,115
1964	31	19	2	31	3	86	994	1,079
1965	35	20	5	32	9	101	814	915
1966	61	41	4	39	4	148	410	559
1967	35	20	4	24	12	96	250	346
1968	36	24	4	44	11	118	242	361
1969	36	34	4	35	4	112	230	342
1970	38	95	4	118	16	271	230	501
1971	37	84	5	68	18	213	228	441
1972	25	45	5	52	52	179	228	407
1973	27	39	5	34	5	110	226	335
1974	33	98	6	92	39	268	32	300
1975	28	108	6	188	91	420	24	444
1976	33	103	6	172	182	497	44	541
1977	31	105	6	212	167	522	21	543
1978	28	63	7	153	163	414	21	435
1979	25	44	9	64	90	232	20	252
1980	22	50	10	49	163	294	20	314
1981	26	109	9	151	170	465	20	485
1982	25	125	9	268	248	675	20	695
1983	26	116	5	154	371	672	20	692
1984	27	134	11	125	251	548	20	568
1985	20	100	5	66	109	300	20	320
1986	14	66	4	35	84	205	20	225
1987	15	28	3	29	17	93	20	113
1988	17	29	3	16	12	77	20	97
1989	12	32	4	24	15	87	20	107
1990	10	24	3	26	18	81	20	101
1991	11	30	3	38	31	113	20	132

¹Semifabricated forms such as rod, sheet, etc., at consumers are not included. Data may not add to totals shown because of independent rounding.

²Stocks held by miscellaneous manufacturers, foundries, and chemical plants. Data for the years 1955-64 estimated based on partial data.

³Inventories held by primary and secondary refineries.

⁴Data from Commodity Exchange Inc., New York.

⁵General Services Administration Inventory of the National Defense Stockpile.

TABLE 4
PRODUCTIVITY¹ IN THE U.S. COPPER INDUSTRY, BY ACTIVITY

	1987	1988	1989	1990	1991	
COPPER MINE PRODUCTION						
Ore concentrated and leached	metric tons	202,632,000	223,576,000	237,301,000	249,500,000	276,891,000
Copper recovered	do.	1,154,181	1,341,279	1,438,627	¹ 1,543,879	1,588,106
Average yield of copper	percent	.57	.60	.61	.62	.57
Copper from in situ leach	metric tons	70,136	49,299	34,485	² 22,997	27,684
Total production ²	do.	1,224,317	1,390,578	1,473,112	1,566,876	1,615,790
MINE AND SX-EW PLANT LABOR						
Average annual workers ³		11,924	11,873	12,421	12,924	13,706
Employee-hours worked		23,197,110	25,707,013	29,371,885	26,314,237	28,668,618
PRODUCTIVITY AT MINES						
(hours per ton)		18.95	18.49	19.94	16.79	17.74
REFINED COPPER PRODUCTION						
Electrolytic copper	metric tons	1,276,933	1,525,470	¹ 1,541,542	1,511,366	1,454,374
PRODUCTIVITY AT PLANTS⁴						
(hours per ton)		9.48	8.19	8.17	¹ 8.32	8.43
INDUSTRY PRODUCTIVITY						
(hours per ton)		28.43	26.68	28.11	² 25.11	26.17

¹Revised.

²Employee-hours per metric ton mined and processed.

³Production from byproduct mines not included.

⁴Includes mine, mill, SX-EW (solvent extraction and electrowinning) plant, and administrative workers at copper open pit and underground mines. Construction workers and workers at mines developing, on standby, or care and maintenance are included. Mines producing copper as a byproduct are not included.

⁵U.S. Bureau of Mines estimates based on unpublished Department of Labor data.

Sources: U.S. Department of Labor and Mine Safety and Health Administration and U.S. Bureau of Mines, production statistics.

TABLE 5
MAJOR U.S. COPPER-PRODUCING COMPANY RESERVES IN 1991

Company and deposit	Percent company ownership	Ore (thousand metric tons)	Percent copper	Copper content (thousand metric tons)	Deposit and company share, thousand tons copper	Deposit and company percent of grand total
ASARCO Incorporated:¹						
Copper deposits:						
Mission Complex, AZ	100.0	530,629	0.67	3,555	3,555	10.4
Ray, AZ	100.0	552,868	.68	3,760	3,760	11.0
Silver Bell, AZ	100.0	91,938	.47	432	432	1.3
Continental, MT	49.9	339,407	.30	1,018	508	1.5
Total copper deposits	XX	1,514,842	.58	8,765	8,255	24.2
Byproduct deposits:						
Coeur, ID	50.0	327	.80	3	1	(^o)
Galena, ID	37.5	679	.52	4	1	(^o)
Troy, MT	75.0	21,410	.68	146	109	.3
Total byproduct deposits	XX	22,416	.68	152	112	.3
Total reserves	XX	1,537,258	.58	8,917	8,367	24.4
Copper Range Co.:³						
White Pine, MI	100.0	175,994	1.12	1,971	1,971	5.8
Cyprus Minerals Co.:⁴						
Bagdad	100.0	672,587	.40	2,690	2,690	8.0
Sierrita/Twin Buttes	100.0	477,724	.30	1,433	1,433	4.2
Miami	100.0	193,230	.45	870	870	3.0
Casa Grande	100.0	14,061	.76	107	107	.3
Mineral Park	100.0	10,342	.27	28	28	.1
Total reserves	XX	1,367,944	.37	5,128	5,128	15.6
Kennecott Corp.:⁵						
Bingham Canyon	100.0	954,990	.60	5,730	5,730	17.0
Magma Copper Co.:⁶						
Magma Superior	100.0	1,278	6.54	84	84	.2
San Manuel:						
Oxide pit	100.0	27,975	.45	126	126	.4
Do.	100.0	3,477	.17	6	6	(^o)
In situ leach ores ⁷	100.0	185,533	.36	674	674	2.0
Underground sulfide	100.0	67,342	.71	477	477	1.4
Open pit sulfide	100.0	627	.90	6	6	(^o)
Kalamazoo underground:						
Sulfide reserves	100.0	15,477	.72	111	111	.3
Deep sulfide	100.0	129,986	.71	919	919	2.7
Pinto Valley:						
Dump leach (sulfide)	100.0	391,251	.14	532	532	1.6
Miami tailings leach	100.0	26,248	.34	90	90	.3
Open pit sulfide	100.0	160,584	.37	601	601	1.8
Leach ore sulfide ⁷	100.0	57,694	.20	117	117	.3
Robinson, Nevada						
Open pit sulfide	100.0	182,693	.61	1,105	1,105	3.2
Total reserves	XX	1,250,165	.39	4,848	4,848	14.2
Phelps Dodge Corp.:⁸						
Morenci, AZ	85.0	567,354	.77	4,369	3,713	11.0
Leaching	85.0	836,787	.34	2,845	2,418	7.0
Chino, NM	66.7	266,350	.70	1,864	1,243	3.4

See footnotes at end of table.

TABLE 5-Continued
MAJOR U.S. COPPER-PRODUCING COMPANY RESERVES IN 1991—Continued

Company and deposit	Percent company ownership	Ore (thousand metric tons)	Percent copper	Copper content (thousand metric tons)	Deposit and company share, thousand tons copper	Deposit and company percent of grand total
Leaching	66.7	153,949	0.30	462	308	0.9
Burro Chief, NM leach ^a	100.0	146,964	.36	529	529	1.5
Total reserves	XX	1,971,404	.51	10,069	8,211	23.8
Grand total, major companies	XX	7,257,754	.51	36,659	34,251	93.4

^aEstimated. XX Not applicable.

¹Source: ASARCO Incorporated 1991 Annual Report, p. 34.

²Less than 0.05%.

³Source: Metall Mining Corp. Annual Report 1991, White Pine Mine, p. 8.

⁴Source: Cyprus Minerals Co. 1991 Annual Report, p. 28.

⁵Source: RTZ Corp. Form 20F, ending Dec. 31, 1991.

⁶Source: Magma Copper Co. 1991 10K Report, p. 18. Reserves are based on mining costs of about \$0.80 per pound of copper.

⁷About 50% of the in situ reserves shown here are estimated to be recoverable according to the company.

⁸Source: Phelps Dodge Corp. 1991 Annual Report, p. 14.

TABLE 6
COPPER SULFATE PRODUCERS IN THE UNITED STATES IN 1991

Company	Plant location
BIT Manufacturing Inc.	Copperhill, TN.
CP Chemicals Inc.	Sewaren, NJ and Sumpter, SC.
Kocide Chemical Corp.	Casa Grande, AZ.
Old Bridge Chemicals ¹	Old Bridge, NJ.
Phelps Dodge Corp.	El Paso, TX.
Southern California Chemical Co.	Santa Fe Springs, CA, Union, IL, Garland, TX.

¹Previously known as Madison Industries, Inc.

TABLE 7
APPARENT CONSUMPTION OF COPPER, BY END-USE SECTOR¹

(Thousand metric tons of copper and percent of consumption)

Year	Electrical ²		Construction		Machinery		Transportation		Ordinance		Other uses		Total consumption (quantity) ³
	Quantity	Percent	Quantity	Percent	Quantity	Percent	Quantity	Percent	Quantity	Percent	Quantity	Percent	
1961	728	48	303	20	228	15	106	7	30	2	121	8	1,517
1962	820	50	328	20	246	15	115	7	33	2	98	6	1,640
1963	822	48	377	22	274	16	120	7	34	2	86	5	1,712
1964	870	49	409	23	231	13	124	7	36	2	107	6	1,776
1965	1,031	52	416	21	238	12	139	7	40	2	119	6	1,982
1966	1,064	48	465	21	266	12	177	8	155	7	89	4	2,216
1967	918	50	367	20	220	12	129	7	147	8	55	3	1,836
1968	974	51	382	20	210	11	134	7	134	7	76	4	1,909
1969	1,009	49	432	21	247	12	144	7	144	7	82	4	2,058
1970	1,000	55	346	19	182	10	127	7	91	5	73	4	1,819
1971	1,038	55	377	20	189	10	132	7	57	3	94	5	1,886
1972	1,264	59	386	18	193	9	129	6	64	3	107	5	2,142
1973	1,378	62	378	17	178	8	133	6	44	2	111	5	2,223
1974	1,287	60	365	17	214	10	129	6	43	2	107	5	2,145
1975	914	62	236	16	118	8	88	6	44	3	74	5	1,473
1976	1,154	60	327	17	154	8	154	8	19	1	115	6	1,924
1977	1,242	60	373	18	186	9	145	7	21	1	103	5	2,070
1978	1,422	60	427	18	190	8	166	7	47	2	118	5	2,370
1979	1,412	58	463	19	219	9	170	7	24	1	146	6	2,434
1980	1,438	66	327	15	174	8	109	5	22	1	109	5	2,179
1981	1,590	70	273	12	159	7	136	6	23	1	91	4	2,271
1982	1,251	71	229	13	123	7	70	4	18	1	70	4	1,762
1983	1,368	68	322	16	161	8	80	4	20	1	60	3	2,012
1984	1,397	66	359	17	148	7	106	5	21	1	85	4	2,116
1985	1,480	69	343	16	150	7	86	4	21	1	64	3	2,144
1986	1,411	66	385	18	150	7	107	5	21	1	64	3	2,138
1987	1,538	70	373	17	132	6	66	3	22	1	66	3	2,197
1988	1,594	72	332	15	133	6	66	3	22	1	66	3	2,214
1989	1,570	72	327	15	131	6	65	3	22	1	65	3	2,181
1990	1,561	72	325	15	108	5	87	4	22	1	65	3	2,168
1991	1,594	75	234	11	106	5	106	5	42	2	43	2	2,125

¹Copper Development Association (CDA) categories have been redistributed on a copper content basis (the alloy component has been subtracted). The electrical component has been extracted from all end-use categories except electrical and ordinance. Adjustments were also made for the new scrap component, which was subtracted. Ordinance data reflect U.S. Department of Commerce ACM military shipments to 1983; estimated data, thereafter, reflect CDA data for 1989.

²Includes wire and other forms used in electrical, communications, and other special uses.

³Data may not add to totals shown because of independent rounding.

TABLE 8
WORLD MINE, SMELTER, AND REFINERY CAPACITIES IN 1991

(Thousand metric tons, primary and secondary copper)

Continent and country	Rated capacity			Continent and country	Rated capacity		
	Mine	Smelter	Refinery		Mine	Smelter	Refinery
North America:				Africa:			
Canada	976	627	650	Botswana	24	26	—
Mexico	360	360	250	Morocco	28	—	—
United States	1,961	1,813	2,551	Namibia	55	60	—
Total¹	3,296	2,800	3,450	South Africa, Republic of	204	256	172
Central and South America:				Zaire	253	285	150
Brazil	61	140	125	Zambia	598	506	605
Chile	2,049	1,480	1,357	Zimbabwe	16	35	29
Peru	430	348	288	Other ²	1	2	3
Other ³	15	7	6	Total¹	1,178	1,169	958
Total¹	2,553	1,975	1,776	Asia:			
Europe:				Burma	10	—	—
Albania	16	19	17	China	492	655	608
Austria	—	45	50	India	75	58	48
Belgium	—	172	480	Indonesia	150	—	—
Bulgaria	46	131	80	Iran	97	100	70
Czechoslovakia	11	25	27	Japan	22	1,355	1,250
Denmark	—	5	5	Korea, North	15	—	25
Finland	18	100	100	Korea, Republic of	5	185	200
France	1	17	47	Malaysia	30	—	—
Germany:				Mongolia	140	—	—
Eastern states	1	25	86	Oman	20	22	20
Western states	—	429	537	Philippines	218	138	173
Hungary	—	4	18	Taiwan	—	—	5
Italy	1	96	128	Total¹	1,273	2,513	2,398
Netherlands	—	8	—	Of which:			
Norway	21	35	40	Nonmarket economy	647	655	633
Poland	460	414	435	Market economy	626	1,858	1,765
Portugal	181	10	10	Oceania:			
Romania	27	98	85	Australia	402	285	335
Spain	40	196	252	Papua New Guinea	172	—	—
Sweden	92	105	107	Total	574	285	335
Turkey	82	81	123	Total world	10,668	12,070	12,990
U.S.S.R.	650	1,055	1,112	Of which:			
United Kingdom	1	80	159	Nonmarket economy	1,863	2,401	2,407
Yugoslavia	145	179	174	Market economy	8,805	9,669	10,583
Other	2	—	—				
Total¹	1,793	3,329	4,072				
Of which:							
Nonmarket economy	1,210	1,746	1,774				
Market economy	583	1,583	2,298				

¹Data may not add to totals shown because of independent rounding.

²Includes mine capacity of 1,000 tons for the Republic of the Congo (Brazzaville), a nonmarket economy country.

³Includes mine capacity of 6,000 tons for Cuba, a non-market economy country.

TABLE 9
COPPER RESERVES AND RESERVE BASE IN 1991

(Million metric tons, contained copper)

Area and country	Reserves	Reserve base
North and Central America:		
Canada	11	23
Mexico	14	20
Panama	—	10
Puerto Rico	—	2
United States	45	90
Other	—	1
Total	70	146
South America:		
Argentina	—	7
Brazil	1	11
Chile	88	140
Peru	7	25
Other	—	3
Total	96	186
Europe:		
Finland	1	1
Norway	1	1
Poland	20	36
Portugal	3	3
Spain	1	1
Sweden	1	1
U.S.S.R.	37	54
Yugoslavia	4	4
Other	2	2
Total	70	103
Africa:		
Namibia	1	3
South Africa, Republic of	2	2
Zaire	10	30
Zambia	12	34
Other	1	1
Total	26	70
Asia:		
China	3	8
India	3	4
Indonesia	11	17
Iran	3	5
Japan	1	1
Mongolia	3	3
Philippines	7	11
Turkey	1	2
Other	3	3
Total	35	54
Oceania:		
Australia	7	21
Papua New Guinea	4	7
Total	11	28
Grand total	308	587

TABLE 10
COPPER CONSUMPTION TRENDS, 1950-2005

(Thousand metric tons and annual percentage consumption growth rates)

Year	United States		Western World	World total
	Apparent total ¹	Reported refined	Refined copper ²	
1950	1,337	1,292	2,502	2,774
1988	2,213	2,211	8,306	10,697
1990	2,168	2,150	8,762	10,605
1991	2,125	2,050	8,887	10,812
2000 (forecast)	2,600	—	11,800	14,630
2005 (forecast)	2,780	—	14,100	17,900
Annual growth rates				
1950-88	1.34%	—	3.20%	3.64%
1990-91	-1.98%	-4.30%	-1.42%	1.95%
1991-2000 (forecast)	2.56%	—	3.20%	3.46%
1991-2005 (forecast)	1.95%	—	3.35%	3.70%

¹U.S. apparent consumption equals primary production plus old scrap plus net imports of refined plus net imports of refined plus refined stock changes.

²World copper consumption is measured in terms of refined copper consumption only. Old copper metal in direct melt scrap is excluded.

Source: U.S. Bureau of Mines, Oct. 1992.

TABLE 11

WORLD COPPER MINE CAPACITY TRENDS

(Thousand metric tons, recoverable copper)

Area and type of mine capacity	At operating mines			At developing mines			Potential in exploration			At mines closed in 1991			Total capacity		
	1993	1997	2005	1993	1997	2005	1993	1997	2005	1993	1997	2005	1993	1997	2005
Africa:															
SX-EW	288	343	323	5	10	10	—	—	5	—	—	—	293	353	338
Other	848	721	728	5	13	13	—	—	68	29	83	40	882	817	849
Total	1,136	1,064	1,051	10	23	23	—	—	73	29	83	40	1,175	1,170	1,187
Asia/Middle East:															
SX-EW	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Other	1,434	1,631	1,653	33	168	165	—	16	217	—	—	46	1,467	1,815	2,081
Total	1,434	1,631	1,653	33	168	165	—	16	217	—	—	46	1,467	1,815	2,081
Europe:															
SX-EW	1	1	—	—	—	—	—	—	—	—	—	—	1	1	—
Other	1,745	1,778	1,630	12	17	5	—	45	395	—	1	—	1,757	1,841	2,030
Total	1,746	1,779	1,630	12	17	5	—	45	395	—	1	—	1,758	1,842	2,030
Oceania:															
SX-EW	11	11	3	10	14	—	—	2	—	—	—	—	21	27	3
Other	566	527	490	—	20	20	—	4	14	—	—	200	566	551	724
Total	577	538	493	10	34	20	—	6	14	—	—	200	587	578	727
North America:															
SX-EW	567	614	388	18	62	81	—	39	131	—	—	—	585	715	600
Other	2,682	2,493	1,868	110	288	272	—	81	829	21	82	153	2,813	2,944	3,122
Total	3,249	3,107	2,256	128	350	353	—	120	960	21	82	153	3,398	3,659	3,722
South America:															
SX-EW	240	344	260	20	205	195	—	60	250	—	—	—	260	609	705
Other	2,395	2,210	1,707	43	289	337	1	188	1,307	—	—	—	2,439	2,687	3,351
Total	2,635	2,554	1,967	63	494	532	1	248	1,557	—	—	—	2,699	3,296	4,056
World:															
SX-EW	1,107	1,313	974	53	291	286	—	101	386	—	—	—	1,160	1,705	1,646
Other	9,670	9,360	8,076	203	795	812	1	334	2,830	50	166	439	9,924	10,655	12,157
Total	10,777	10,673	9,050	256	1,086	1,098	1	435	3,216	50	166	439	11,084	12,360	13,803

TABLE 12
MINE PRODUCTION OF RECOVERABLE COPPER IN THE UNITED STATES, BY MONTH AND STATE

(Metric tons)

	1987	1988	1989	1990	1991
Month:					
January	101,563	110,863	127,219	*126,752	135,847
February	92,154	102,507	121,520	*115,329	126,251
March	105,904	120,936	134,238	*123,527	138,178
April	98,040	111,851	125,551	*124,254	129,274
May	104,404	120,981	127,892	*133,934	147,433
June	102,007	115,826	121,788	*134,374	136,598
July	104,000	116,131	122,547	*137,509	138,937
August	107,004	128,163	127,547	*137,058	141,006
September	105,180	120,031	122,519	*136,907	131,207
October	104,586	123,646	125,204	*141,994	140,986
November	108,324	121,308	118,197	*139,959	131,427
December	110,430	124,685	123,596	*136,145	133,934
Total	1,243,596	1,416,928	1,497,818	*1,587,742	1,631,078
State:					
Arizona	751,031	842,728	898,466	978,767	1,024,066
Michigan, Montana, and Utah	222,432	295,489	314,313	322,301	337,137
New Mexico	246,532	258,660	259,640	262,815	252,859
Other States ¹	23,601	20,051	25,399	*23,859	17,016
Total	1,243,596	1,416,928	1,497,818	*1,587,742	1,631,078

¹Revised.

¹Includes Colorado, Idaho, Illinois, Missouri, Oregon, and Tennessee; in addition, 1987 includes Washington; 1988 and 1989 includes California and Nevada; 1990 includes California, Kentucky, and Nevada; and 1991 California and Nevada.

TABLE 13
TWENTY-FIVE LEADING COPPER-PRODUCING MINES IN THE UNITED STATES IN 1991, IN ORDER OF OUTPUT

Rank	Mine	County and State	Operator	Source of copper	Capacity (thousand metric tons)
1	Morenci	Greenlee, AZ	Phelps Dodge Corp.	Copper-molybdenum ore, concentrated and leached	365
2	Bingham Canyon	Salt Lake, UT	Kennecott, Utah Copper Corp.	do.	245
3	San Manuel	Pinal, AZ	Magma Copper Co.	do.	170
4	Chino	Grant, NM	Phelps Dodge Corp.	do.	155
5	Tyrone	do.	Phelps Dodge Corp. and Burro Chief Copper Co.	Copper ore, concentrated and leached	170
6	Sierrita	Pima, AZ	Cyprus Sierrita Corp.	Copper-molybdenum ore, concentrated and leached	117
7	Ray	Pinal, AZ	ASARCO Incorporated	Copper ore, concentrated and leached	125
8	Bagdad	Yavapai, AZ	Cyprus Bagdad Copper Co.	Copper-molybdenum ore, concentrated and leached	116
9	Pinto Valley	Gila, AZ	Pinto Valley Copper Corp.	do.	92
10	Mission Complex	Pima, AZ	ASARCO Incorporated	Copper ore, concentrated	80
11	Inspiration	Gila, AZ	Cyprus Miami Mining Corp.	Copper ore, leached	65
12	White Pine	Ontonagon, MI	Copper Range Co.	Copper ore, concentrated	60
13	Continental	Silver Bow, MT	Montana Resources Inc.	Copper-molybdenum ore, concentrated	50
14	Twin Buttes	Pima, AZ	Cyprus Sierrita Corp.	Copper ore, leached	20
15	Troy	Lincoln, MT	ASARCO Incorporated	Copper-silver ore, concentrated	18
16	San Xavier	Pima, AZ	do.	Copper ore, concentrated	15
17	Superior (Magma)	Pinal, AZ	Magma Copper Co.	do.	13
18	Miami	Gila, AZ	Pinto Valley Copper Corp.	Copper ore, leached	10
19	Casteel	Iron, MO	The Doe Run Co.	Lead-copper ore, concentrated	NA
20	Silver Bell	Pima, AZ	ASARCO Incorporated	Copper ore, concentrated	5
21	Lakeshore	Pinal, AZ	Cyprus Case Grande Corp.	Copper ore, leached	10
22	Johnson	Cochise, AZ	Arimetco Incorporated	do.	4
23	Oracle Ridge	Pinal, AZ	South Atlantic Ventures Ltd.	Copper ore, concentrated	NA
24	Yerington	Lyon, NV	Arimetco Incorporated	Copper ore, leached	5
25	Mineral Park	Mohave, AZ	Cyprus Mineral Park	Copper ore, concentrated	NA

NA Not available.

TABLE 14
MINE PRODUCTION OF COPPER-BEARING ORES AND RECOVERABLE COPPER CONTENT OF ORES PRODUCED IN THE UNITED STATES, BY SOURCE AND TREATMENT PROCESS

(Metric tons)

Source and treatment process	1987		1988		1989		1990		1991	
	Gross weight	Recoverable copper								
Mined copper ore:										
Concentrated	201,434,000	991,857	222,268,000	1,113,287	230,526,000	1,126,742	240,618,000	1,150,416	261,204,000	1,146,865
Leached ¹	1,198,000	162,324	1,308,000	227,992	6,775,000	311,885	8,882,000	393,463	15,687,000	441,241
Total	202,632,000	1,154,181	223,576,000	1,341,279	237,301,000	1,438,627	249,500,000	1,543,879	276,891,000	1,588,106
Copper precipitates shipped; leached from tailings, dump, and in-place material	110,511	70,136	69,683	49,299	47,388	34,485	31,344	22,997	41,370	27,684
Other copper-bearing ores ²	36,041,000	19,279	10,685,000	26,351	15,285,000	24,707	10,111,000	20,866	8,999,000	15,288
Grand total ³	XX	1,243,596	XX	1,416,928	XX	1,497,818	XX	1,587,742	XX	1,631,078

¹Revised. XX Not applicable.²Includes electronron from concentrates roast-leached.³Includes copper-lead ore, gold ore, gold-silver ore, lead ore, lead-zinc ore, molybdenum ore, silver ore, tungsten ore, zinc ore, fluorapatite, flux ores, clean-up, ore shipped directly to smelters, and tailings.⁴Does not include lead ore to avoid disclosing company proprietary data.⁵Data may not add to totals shown because of independent rounding.

TABLE 15
**RECOVERABLE COPPER, GOLD, AND SILVER CONTENT
 OF CONCENTRATED COPPER ORE IN 1991**

State	Ore concentrated (thousand metric tons)	Recoverable metal content				Value of gold and silver per metric ton of ore
		Copper		Gold (troy ounces)	Silver (troy ounces)	
		Metric tons	Percent			
Arizona	167,860	719,099	0.42	50,775	4,651,017	\$0.22
Other ¹	93,344	427,766	.46	W	10,756,565	W
Total or average	261,204	1,146,865	.45	W	15,407,582	W

W Withheld to avoid disclosing company proprietary data.

¹Includes Michigan, Montana, Nevada, New Mexico, and Utah.

TABLE 16
BLISTER AND ANODE COPPER PRODUCED IN THE UNITED STATES,
BY SOURCE OF MATERIAL

(Metric tons, copper content)

Period	Domestic and foreign ores ²	Scrap	Total
1987	972,141	276,640	1,248,781
1988	1,042,961	331,612	1,374,573
1989	1,120,445	359,066	1,479,511
1990	¹ 1,158,462	304,860	¹ 1,463,322
1991:			
January	98,210	30,878	129,088
February	94,588	27,064	121,652
March	90,731	33,335	124,066
April	91,713	33,788	125,501
May	91,197	29,376	120,573
June	84,255	30,263	114,518
July	88,424	28,487	116,911
August	92,188	32,514	124,702
September	102,275	25,751	128,026
October	104,031	32,544	136,575
November	94,613	31,407	126,020
December	90,701	28,924	119,625
Total	1,122,926	364,331	1,487,257

¹Revised.

²Includes blister, anode, and black copper from primary or secondary sources.

³Includes electrowon from concentrates roast/leached.

TABLE 17
PRODUCTION OF REFINED COPPER, BY SOURCE AND METHOD OF RECOVERY

(Metric tons)

Period	Primary materials			Scrap			Total refined ²	
	Electrolytically refined ¹		Electrowon	Electrolytically refined ¹	Fire refined	Total ²		
	Domestic ³	Foreign						
1987	4965,621	W	161,287	1,126,908	311,312	103,426	414,738	1,541,646
1988	1,054,378	123,650	227,992	1,406,020	347,442	98,985	446,427	1,852,447
1989	1,039,862	125,085	311,885	1,476,833	376,595	103,424	480,018	1,956,851
1990	1,108,550	74,620	393,463	1,576,633	328,196	112,561	440,757	2,017,390
1991:								
January	95,134	6,293	29,120	130,547	25,169	10,197	35,366	165,913
February	85,040	5,706	30,070	120,816	23,939	8,301	32,240	153,056
March	88,005	5,982	34,443	128,430	31,482	9,050	40,532	168,962
April	85,175	7,365	34,713	127,253	29,581	10,002	39,583	166,836
May	93,334	6,470	39,516	139,320	28,651	9,589	38,240	177,560
June	79,369	4,986	36,999	121,354	27,048	8,665	35,713	157,067
July	87,675	4,252	38,515	130,442	28,473	4,126	32,599	163,041
August	87,147	6,470	38,518	132,135	23,657	9,387	33,044	165,179
September	87,984	7,099	39,196	134,279	21,170	7,301	28,471	162,750
October	94,224	4,952	41,814	140,990	28,229	9,108	37,337	178,327
November	89,539	9,048	38,786	137,373	25,424	6,658	32,082	169,455
December	86,679	8,265	39,551	134,495	25,361	7,194	32,555	167,050
Total ²	1,059,303	76,889	441,241	1,577,433	318,182	99,575	417,761	1,995,194

W Withheld to avoid disclosing company proprietary data.

¹Based on source of material at smelter level.

²Data may not add to total source and method of recovery because of independent rounding.

³Includes fire-refined copper.

⁴Includes primary and foreign materials.

TABLE 18
APPARENT CONSUMPTION OF COPPER POWDER AND FLAKES IN
THE UNITED STATES

Year	Production (metric tons)	Imports		Exports		Apparent consumption ² (metric tons)
		Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value (thousands)	
1978	16,992	1,153	\$4,300	1,713	\$4,597	16,432
1979	17,411	1,062	4,832	1,781	6,453	16,692
1980	13,203	896	4,675	1,766	6,397	12,333
1981	13,594	1,239	5,635	1,129	4,441	13,704
1982	9,686	1,064	4,521	959	3,834	9,791
1983	11,455	1,400	5,300	786	2,799	12,069
1984	12,783	1,490	5,594	893	3,419	13,380
1985	9,776	1,143	4,864	1,141	4,074	9,778
1986	7,898	1,277	5,462	1,367	5,353	7,808
1987	8,440	1,154	6,099	2,240	11,239	7,354
1988	9,370	1,430	9,514	2,664	11,074	8,136
1989	8,591	1,369	9,042	2,452	9,842	7,508
1990	8,525	1,486	9,658	2,447	9,021	7,564
1991	7,794	1,396	10,294	3,302	13,882	5,888

¹Cost, insurance, and freight (c.i.f.) value at U.S. port.

²Production plus imports minus exports.

Sources: U.S. Bureau of Mines and U.S. Department of Commerce, Bureau of the Census.

TABLE 19
PRODUCTION, SHIPMENTS, STOCKS, IMPORTS, AND EXPORTS OF
COPPER SULFATE IN THE UNITED STATES

(Metric tons)

Year	Production		Shipments	Stocks, Dec. 31	Imports	Exports
	Quantity	Copper content				
1987	33,340	8,418	35,338	2,969	¹ 4,764	NA
1988	34,184	8,630	32,943	4,210	¹ 10,677	NA
1989	33,187	8,349	33,912	3,485	¹ 13,458	571
1990	¹ 34,286	¹ 8,627	¹ 36,357	¹ 1,414	¹ 12,251	559
1991	40,186	10,104	39,220	2,380	10,309	827

NA Not available. ¹Revised.

¹Includes consumption by producing companies.

TABLE 20
BYPRODUCT SULFURIC ACID (100% BASIS) PRODUCED IN THE
UNITED STATES¹

Plant type	1987	1988	1989	1990	1991
Copper ²	2,542,602	2,892,655	3,075,859	3,380,940	3,819,439
Lead ³	116,311	133,672	155,899	165,283	127,121
Zinc ⁴	410,460	416,617	409,564	412,682	418,927
Total	3,069,373	3,442,944	3,641,322	3,958,905	4,365,487

¹Includes acid from foreign materials.

²Excludes acid made from pyrite concentrates.

³Includes acid produced at molybdenum plants to avoid disclosing company proprietary data.

⁴Excludes acid made from native sulfur.

TABLE 21
CONSUMPTION OF COPPER AND BRASS MATERIALS IN THE UNITED
STATES, BY ITEM

(Metric tons)

Item	Brass mills	Wire rod mills	Foundries, chemical plants, miscellaneous users	Secondary smelters-refiners ¹	Total
1990:					
Copper scrap	² 754,386	W	³ 75,645	777,833	¹ 1,607,864
Refined copper ³	⁴ 445,221	1,653,490	⁴ 47,236	4,479	2,150,426
Hardeners and master alloys	906	—	3,269	—	4,175
Brass ingots	—	—	¹ 136,468	—	¹ 136,468
Slab zinc	73,728	—	² 27,444	3,103	¹ 104,275
Miscellaneous	—	—	—	179	179
1991:					
Copper scrap	² 695,199	W	55,682	802,138	1,553,019
Refined copper ³	414,327	1,591,767	⁴ 42,229	W	2,048,323
Hardeners and master alloys	757	—	2,726	—	3,483
Brass ingots	—	—	117,151	—	117,151
Slab zinc	73,888	—	21,108	2,955	97,951
Miscellaneous	—	—	—	90	90

¹Revised. W Withheld to avoid disclosing company proprietary data.

²Includes ingotmakers.

³Includes consumption of copper scrap at wire rod mills to avoid disclosing company proprietary data.

⁴Detailed information on consumption of refined copper can be found in table 23.

⁵Includes consumption of refined copper at secondary smelters-refiners to avoid disclosing company proprietary data.

TABLE 22
APPARENT CONSUMPTION OF COPPER IN THE UNITED STATES

(Metric tons)

Period	Refined copper production	Copper in old scrap	Net refined imports	Stock change during period	Apparent consumption
1987	1,126,908	497,937	459,962	(111,733)	2,196,540
1988	1,406,020	518,179	273,346	(16,223)	2,213,768
1989	1,476,833	547,561	170,092	9,952	2,184,534
1990	1,576,633	535,656	50,508	(5,382)	2,168,179
1991:					
January	130,547	44,341	(10,977)	5,089	158,822
February	120,816	43,144	5,775	4,314	165,421
March	128,430	50,042	(8,193)	(2,725)	173,004
April	127,253	49,620	14,136	(3,737)	194,746
May	139,320	46,672	(14,038)	4,624	167,330
June	121,354	46,493	(318)	3,118	164,411
July	130,442	41,761	3,066	21,064	154,205
August	132,135	43,234	(3,547)	(21,115)	192,937
September	134,279	40,469	4,933	(10,127)	189,808
October	140,990	46,258	22,962	8,970	201,240
November	137,373	43,259	11,434	9,593	182,473
December	134,495	38,044	135	12,104	160,570
Total ¹	1,577,433	533,338	25,369	31,172	2,104,968

¹Revised.

¹Data may not add to totals shown because of independent rounding.

TABLE 23
REFINED COPPER CONSUMED IN THE UNITED STATES, BY CLASS OF CONSUMER

(Metric tons)

Class of consumer	Cathodes	Wirebars	Ingots and ingot bars	Cakes and slabs	Billets and other	Total
1990:						
Wire rod mills	1,653,490	—	—	—	—	1,653,490
Brass mills	252,116	4,593	30,878	57,900	99,733	445,220
Chemical plants	W	W	—	—	1,086	1,086
Ingotmakers	W	—	W	—	4,479	4,479
Foundries	3,549	1,905	6,440	W	2,656	14,550
Miscellaneous ¹	13,245	111	13,184	W	5,061	31,601
Total	1,922,400	6,609	50,502	57,900	113,015	2,150,426
1991:						
Wire rod mills	1,575,208	—	—	—	16,560	1,591,768
Brass mills	277,858	W	18,235	33,331	84,903	414,327
Chemical plants	W	W	—	—	866	866
Ingotmakers	W	—	W	W	3,376	3,376
Foundries	1,837	W	6,491	W	4,401	12,729
Miscellaneous ¹	W	W	W	W	25,257	25,257
Total	1,854,903	W	24,726	33,331	135,363	2,048,323

W Withheld to avoid disclosing company proprietary data; included with "Billets and other."

¹Includes iron and steel plants, primary smelters producing alloys other than copper, consumers of copper powder and copper shot, and other manufacturers.

TABLE 24
STOCKS OF COPPER IN THE UNITED STATES, END OF PERIOD¹

(Metric tons)

Period	Blister and materials in process of refining ²	Refined copper			Other ³	New York Commodity Exchange	Total ⁴
		Secondary refineries	Wire rod mills	Brass mills			
1987	149,694	29,321	28,433	15,331	22,840	17,000	112,927
1988	121,442	16,301	28,641	16,767	22,995	12,000	96,704
1989	131,650	23,580	31,720	12,447	23,909	15,000	106,656
1990	118,924	26,031	24,294	9,775	23,174	18,000	101,274
1991:							
January	119,715	25,056	34,478	11,019	22,810	13,354	106,717
February	125,355	22,968	37,034	12,866	22,810	15,219	110,897
March	133,587	21,635	24,416	12,090	22,810	27,423	108,374
April	136,496	18,120	24,557	10,727	22,810	28,029	104,243
May	135,738	17,008	31,525	14,496	22,810	22,630	108,469
June	130,052	35,575	19,007	10,565	22,810	24,315	112,272
July	22,923	37,544	29,179	10,488	22,810	33,087	133,108
August	128,085	32,468	15,317	11,311	22,810	30,139	112,045
September	131,846	30,718	17,045	9,207	22,810	21,941	101,721
October	144,681	31,798	21,537	10,605	22,810	24,314	111,064
November	143,333	36,115	23,256	11,162	22,810	27,149	120,492
December	135,099	38,334	29,578	10,724	22,810	30,603	132,049

¹Data formerly presented in thousand metric tons.

²Includes copper in transit from smelters in the United States to refineries therein.

³Includes chemical plants, foundries, and miscellaneous plants; includes 20,000 tons in the National Defense Stockpile.

⁴Data may not add to totals shown because of independent rounding.

TABLE 25
AVERAGE MONTHLY PRICES FOR REFINED COPPER IN THE UNITED STATES AND ON THE LONDON METAL EXCHANGE

(Cents per pound)

Month	1990				1991			
	U.S. producers, delivered price		COMEX first position ³	LME cash Grade A ⁴	U.S. producers, delivered price		COMEX first position ³	LME cash Grade A ⁴
	Cathode ¹	Wirebar ²			Cathode ¹	Wirebar ²		
January	108.64	*119.35	104.36	107.31	114.61	122.59	110.59	111.02
February	111.22	119.35	107.35	107.01	115.01	122.73	110.73	111.05
March	128.41	*136.24	124.24	119.05	113.95	121.24	109.24	109.26
April	126.94	134.38	122.38	121.76	113.13	120.35	108.36	112.09
May	124.57	132.32	120.32	124.30	105.57	113.11	101.11	104.52
June	117.35	124.93	112.93	117.18	103.88	111.72	99.72	100.63
July	126.12	133.91	121.91	125.57	104.34	111.90	99.90	101.40
August	134.96	142.53	130.53	134.06	105.97	113.48	101.48	101.26
September	134.22	142.45	130.46	137.39	111.11	118.92	106.92	105.41
October	130.18	*138.41	126.41	124.39	111.34	118.90	106.90	107.18
November	119.76	127.76	115.75	117.25	110.03	117.26	105.26	107.91
December	115.61	*124.39	112.39	112.69	102.97	110.31	98.31	100.80
Average	123.16	*131.09	119.09	121.02	109.33	116.88	104.88	106.21

¹Revised.

¹Listed as "U.S. producer cathode."

²Listed as "Electrolytic wirebar (Warrenton Refining Co.)."

³Listed as "COMEX high-grade first position."

⁴Based on average monthly rates of exchange.

Sources: Metals Week and American Metal Market.

TABLE 26
U.S. EXPORTS OF UNMANUFACTURED COPPER (COPPER CONTENT), BY COUNTRY

Country	Ore and concentrate		Matte, ash and precipitates		Refined		Unalloyed copper scrap		Blister and anodes		Total	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1990	258,235	\$401,785	31,709	\$40,977	211,164	\$554,833	139,624	\$227,418	6,422	\$14,701	647,154	\$1,239,714
1991:												
Belgium	—	—	56	615	306	712	94	122	—	—	456	1,449
Brazil	36,624	54,028	—	—	18	63	362	706	—	—	37,004	54,797
Bulgaria	5,889	11,587	—	—	—	—	—	—	—	—	5,889	11,587
Canada	40,029	73,433	8,691	6,436	1,883	5,500	32,988	40,400	13,300	32,823	96,891	158,592
China	38,363	30,706	—	—	4,319	9,669	22,873	10,260	107	236	65,662	50,871
Costa Rica	20	20	—	—	881	2,300	—	—	—	—	901	2,320
Finland	7,045	5,887	—	—	3	4	—	—	—	—	7,048	5,891
France	—	—	—	—	1,192	2,326	—	—	2	3	1,194	2,329
Germany	136	168	696	5,729	1,853	4,308	519	900	99	115	3,303	11,220
Hong Kong	28	32	23	26	2,691	6,864	5,485	3,960	551	816	8,778	11,698
India	—	—	—	—	—	—	594	1,008	—	—	594	1,008
Indonesia	77	333	—	—	702	1,853	283	237	—	—	1,062	2,423
Italy	205	106	—	—	1,186	2,367	20	39	—	—	1,411	2,512
Japan	74,854	114,386	256	814	122,987	294,507	23,721	52,805	985	2,206	222,803	464,718
Korea, Republic of	11,458	20,002	397	348	12,088	28,563	29,488	53,864	1,885	4,406	55,316	107,183
Malaysia	—	—	—	—	798	2,060	89	63	—	—	887	2,123
Mexico	2,486	1,438	417	635	7,220	16,676	7,497	9,501	50	124	17,670	28,374
Netherlands	3	10	—	—	3,099	7,128	158	116	—	—	3,260	7,254
Philippines	29,447	22,330	—	—	—	—	23	93	—	—	29,470	22,423
Singapore	—	—	—	—	3,692	9,190	846	851	2	5	4,540	10,046
Spain	2,773	5,443	6	30	5	16	20	5	79	71	2,883	5,565
Taiwan	2,701	4,613	—	—	88,853	205,903	5,908	6,284	4,159	9,116	101,621	225,916
Thailand	—	—	—	—	5,027	12,161	—	—	—	—	5,027	12,161
United Kingdom	339	378	357	351	1,757	4,105	82	145	34	35	2,569	5,014
Venezuela	—	—	—	—	2,140	5,131	—	—	—	—	2,140	5,131
Other	153	113	312	1,232	501	1,150	268	473	41	146	1,275	3,114
Total ¹	252,630	345,013	11,211	16,216	263,201	622,556	131,318	181,833	21,294	50,102	679,654	1,215,720

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 27
U.S. EXPORTS OF COPPER SEMIMANUFACTURES, BY COUNTRY

Country	Pipes and tubing		Plates, sheets, foil, and bars		Bare wire, including wire rod ¹		Wire and cable, stranded		Oxides and hydroxides	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1990	15,998	\$58,153	20,406	\$78,291	19,628	\$78,412	7,165	\$45,676	5,322	\$17,996
1991:										
Australia	691	4,396	(²)	26	28	359	28	416	300	863
Belgium	35	106	13	291	9	32	29	247	44	198
Brazil	57	317	15	48	6	61	8	140	—	—
Canada	7,839	26,216	9,121	29,483	7,719	25,666	2,642	10,282	256	1,022
Chile	19	136	18	30	2	16	55	295	202	192
China	95	317	105	285	122	358	550	1,027	115	507
Colombia	48	149	913	2,367	8	59	26	114	41	112
Dominican Republic	69	43	847	2,236	226	865	39	190	37	96
Ecuador	36	70	31	297	46	186	1	5	10	28
Egypt	448	1,064	795	2,494	2	11	23	74	7	98
El Salvador	36	138	2	5	2	5	109	485	15	71
France	212	591	30	250	8	75	64	1,532	278	793
Germany	220	646	182	1,219	28	416	220	2,958	101	3,835
Greece	46	147	—	—	4	40	(²)	6	309	491
Hong Kong	52	182	394	2,105	97	398	49	2,031	34	102
Israel	440	1,329	83	446	24	379	56	691	39	109
Italy	52	116	35	216	35	218	37	556	105	286
Jamaica	14	37	175	967	26	131	72	298	—	—
Japan	153	328	553	3,033	131	1,102	286	3,074	1,197	3,709
Korea, Republic of	60	197	170	1,783	25	218	50	916	1,500	4,140
Malaysia	616	2,326	87	371	53	372	(²)	13	62	188
Mexico	2,138	7,213	1,509	5,528	13,594	55,157	1,853	8,346	131	369
Netherlands	600	2,116	23	280	8	78	29	388	301	946
New Zealand	45	218	10	111	15	54	6	56	188	579
Philippines	114	356	27	190	149	905	7	77	142	474
Saudi Arabia	1,016	3,595	24	71	88	518	219	1,414	17	53
Singapore	94	353	78	453	49	1,519	55	563	349	1,029
South Africa, Republic of	—	—	2	18	1	32	4	33	103	263
Spain	912	2,891	125	566	3	26	9	62	68	304
Taiwan	741	2,662	1,979	12,311	33	392	31	489	137	440
Thailand	567	2,006	299	1,578	—	—	46	138	48	136
Trinidad and Tobago	21	88	596	1,671	70	256	35	130	4	15
United Kingdom	243	1,102	122	689	111	973	406	4,152	387	1,150
Venezuela	421	1,637	267	758	21	198	128	463	—	—
Other	1,957	6,703	663	2,087	201	1,553	681	3,743	713	2,191
Total ³	20,107	69,789	19,294	74,263	22,944	92,628	7,853	45,404	7,240	24,789

¹Total exports of wire rod for 1990 were 2,814 tons, valued at \$8,949,000.

²Less than 1/2 unit.

³Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 28
U.S. IMPORTS FOR CONSUMPTION OF UNMANUFACTURED COPPER (COPPER CONTENT), BY COUNTRY

Country	Ore and concentrate		Matte, ash and precipitates		Blister and anode		Refined		Unalloyed scrap		Total	
	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)
1990	91,493	\$131,038	7,961	\$19,802	44,278	\$125,238	261,672	\$674,774	35,904	\$80,976	441,308	\$1,031,828
1991:												
Australia	—	—	—	—	—	—	66	481	—	—	66	481
Brazil	—	—	—	—	—	—	25,008	59,419	—	—	25,008	59,419
Canada	—	—	1,755	1,878	2	11	197,923	468,370	19,587	41,238	219,267	511,497
Chile	28	18	—	—	27,908	67,453	49,814	114,453	1,008	2,470	78,758	184,394
Costa Rica	—	—	—	—	—	—	—	—	814	853	814	853
Dominican Republic	—	—	—	—	—	—	—	—	342	304	342	304
Germany	—	—	—	—	114	451	273	703	—	—	387	1,154
Indonesia	10,872	8,361	—	—	—	—	—	—	—	—	10,872	8,361
Jamaica	—	—	—	—	—	—	—	—	563	522	563	522
Japan	—	—	—	—	11,874	32,741	4,497	12,600	—	—	16,371	45,341
Mexico	46,429	55,121	1,713	2,968	1,514	4,318	—	—	3,257	5,543	52,913	67,950
Netherlands	—	—	—	—	—	—	3,668	11,953	79	234	3,747	12,187
Panama	—	—	—	—	—	—	—	—	393	685	393	685
Peru	—	—	—	—	17,924	41,255	5,327	11,996	—	—	23,251	53,251
Portugal	3,434	5,149	(²)	459	—	—	—	—	20	44	3,454	5,652
South Africa, Republic of	—	—	—	—	—	—	150	381	—	—	150	381
Spain	—	—	—	—	—	—	1,005	2,335	40	87	1,045	2,422
Sweden	—	—	—	—	(²)	5	778	1,808	—	—	778	1,813
Venezuela	—	—	—	—	—	—	—	—	1,069	1,124	1,069	1,124
Zaire	—	—	—	—	994	2,380	—	—	—	—	994	2,380
Other	2	12	127	164	—	—	77	195	1,579	1,845	1,785	2,216
Total ³	60,766	68,661	3,594	5,468	60,329	148,617	288,586	684,694	28,751	54,949	442,027	962,387

¹C.i.f value at U.S. port.

²Less than 1/2 unit.

³Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 29
U.S. IMPORTS FOR CONSUMPTION OF COPPER SEMIMANUFACTURES, BY COUNTRY

Country	Pipes and tubing		Plates, sheets, foil, and bars		Bare wire, including wire rod ²		Wire and cable, stranded		Oxides and hydroxides	
	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)
1990	21,123	\$85,175	51,532	\$227,349	2,341	\$12,014	8,768	\$27,620	3,798	\$9,319
1991:										
Australia	5	20	4	14	1	4	(³)	2	2,493	6,833
Belgium	(³)	6	168	1,784	—	—	—	—	15	46
Brazil	21	95	1,311	4,291	(³)	2	—	—	—	—
Canada	3,423	12,775	9,301	32,676	589	1,867	5	88	1	4
Chile	501	1,532	2,420	7,376	19	53	—	—	—	—
Finland	156	992	3,574	14,252	264	1,944	79	106	—	—
France	2,111	8,102	15	125	10	206	1	14	—	—
Germany	303	2,204	4,449	20,405	167	1,459	15	206	(³)	8
Italy	98	483	108	407	18	172	49	850	7	21
Japan	4,322	17,547	9,114	56,009	161	1,821	110	937	48	332
Luxembourg	—	—	557	5,905	—	—	—	—	—	—
Mexico	2,005	7,270	723	2,368	20	98	306	1,149	1,481	3,726
Netherlands	—	—	38	164	96	460	—	—	—	—
Norway	—	—	—	—	—	—	—	—	345	894
Peru	8	19	440	1,283	83	147	1,398	3,700	—	—
Poland	—	—	22	70	180	451	174	519	—	—
Sweden	34	165	13,326	50,445	(³)	47	(³)	4	—	—
Taiwan	4	22	196	1,272	11	142	23	164	—	—
Turkey	—	—	—	—	30	113	17	67	—	—
United Kingdom	67	713	1,129	10,505	18	299	1	69	298	763
Venezuela	—	—	—	—	—	—	152	544	—	—
Other	15	127	455	1,395	329	1,576	28	100	2	—
Total	13,073	52,072	47,350	210,746	1,996	10,861	2,358	8,519	4,690	12,627

¹C.i.f. value at U.S. port. Values for years prior to 1989 were customs values.

²Total imports of wire rod for 1990 were 73 tons, valued at \$434,308.

³Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 30
COPPER: WORLD MINE PRODUCTION, BY COUNTRY¹

(Thousand metric tons)

Country	1987	1988	1989	1990	1991 ^a
Albania ^a	¹ 12.5	¹ 13.3	¹ 14.0	¹ 11.5	6.1
Argentina	.4	.5	.7	¹ .3	.4
Australia	232.7	238.3	296.0	¹ 330.0	² 311.0
Bolivia	(¹)	.2	.3	.2	(¹)
Botswana ⁴	18.9	24.4	21.7	20.6	20.5
Brazil	40.3	44.8	¹ 47.4	¹ 36.4	37.0
Bulgaria ^a	44.0	47.0	48.0	¹ 30.0	30.0
Burma	10.6	4.7	5.1	¹ 4.4	² 5.7
Canada:					
By concentration or cementation	¹ 798.3	¹ 772.5	¹ 719.0	¹ 798.3	773.4
Leaching (electrowon)	3.9	¹ 4.0	¹ 4.0	¹ 3.7	3.5
Chile ⁵	¹ 1,418.1	¹ 1,451.0	¹ 1,609.3	¹ 1,588.4	² 1,814.3
China ^a	250.0	¹ 282.0	¹ 276.0	¹ 300.0	300.0
Congo	1.3	1.0	—	—	—
Cuba	3.5	3.0	¹ 1.8	¹ 2.8	3.0
Cyprus ⁶	.1	.3	¹ .5	¹ .5	² .5
Czechoslovakia ⁷	5.3	¹ 5.0	4.9	¹ 3.3	2.5
Ecuador ^a	.1	.1	.1	.1	.1
Finland	20.4	20.2	14.5	¹ 12.6	² 11.7
France	.3	.5	1.0	¹ .5	² .3
Germany:					
Eastern states	¹ 11.0	¹ 10.4	¹ 7.4	¹ 5.5	—
Western states ⁷	1.5	.7	.1	—	—
Total	¹ 12.5	¹ 11.1	7.5	¹ 5.5	—
Honduras	.6	.6	2.4	¹ 1.4	1.0
India	56.5	55.4	57.4	¹ 61.0	58.8
Indonesia ⁷	102.1	121.5	144.0	178.1	200.0
Iran ^a	40.0	51.0	68.0	¹ 60.3	² 80.7
Japan	23.8	16.7	14.7	¹ 12.9	² 12.4
Korea, North ^a	15.0	15.0	15.0	15.0	15.0
Korea, Republic of	.2	(¹)	(¹)	.1	(¹)
Malaysia	29.9	¹ 22.1	¹ 23.8	¹ 24.3	² 25.6
Mexico:					
By concentration or cementation	244.0	¹ 273.5	¹ 253.9	¹ 293.6	265.0
Leaching (electrowon)	¹ 8.7	11.4	10.3	¹ 26.9	² 32.1
Mongolia	¹ 120.8	¹ 121.8	¹ 123.6	¹ 123.9	93.0
Morocco	16.5	15.4	16.0	¹ 16.4	² 14.2
Mozambique	.2	.1	.1	(¹)	—
Namibia	37.6	40.9	26.9	¹ 26.0	30.0
Nepal	(¹)				
Norway	22.0	15.9	16.5	19.7	² 17.4
Oman	18.1	17.1	¹ 16.6	¹ 14.0	13.0
Papua New Guinea	217.7	218.6	204.0	170.2	² 204.5
Peru: ⁸					
By concentration or cementation	391.1	301.7	353.1	317.7	² 381.2
Leaching (electrowon)	26.5	21.1	19.7	16.3	² 17.9
Philippines	216.1	218.1	¹ 193.0	¹ 182.1	150.0
Poland	438.0	437.0	384.0	¹ 370.0	390.0
Portugal ⁹	1.1	¹ 3.7	103.7	¹ 162.9	165.0

See footnotes at end of table.

TABLE 30—Continued
COPPER: WORLD MINE PRODUCTION, BY COUNTRY¹

(Thousand metric tons)

Country	1987	1988	1989	1990	1991 ^a
Romania ^{a 7}	26.0	26.0	25.0	25.0	20.0
Saudi Arabia	—	^a .3	^a .8	^a .9	^a .9
South Africa, Republic of ^a	188.1	168.5	^a 181.9	^a 178.7	^a 192.9
Spain	16.2	13.8	24.6	^a 15.3	16.0
Sweden	85.0	74.4	69.5	^a 74.7	^a 80.5
Turkey ^a	26.3	30.5	^a 37.1	^a 38.4	38.4
U.S.S.R. ^{a 7}	630.0	640.0	640.0	600.0	550.0
United Kingdom	.8	.7	.5	^a 1.0	^a 2.2
United States: ^{a 7}					
By concentration or cementation	1,082.5	1,191.7	1,185.6	^a 1,194.3	^a 1,189.8
Leaching (electrowon)	161.1	228.0	^a 311.9	^a 393.5	^a 441.2
Yugoslavia ^{a 11}	130.5	103.5	^a 138.9	^a 140.1	138.0
Zaire: ^{a 7}					
By concentration or cementation	208.1	185.7	183.1	^a 120.0	80.0
Leaching (electrowon)	307.5	309.5	283.5	^a 250.0	170.0
Zambia: ^{a 12}					
By concentration or cementation (smelted)	318.7	284.1	^a 330.2	^a 300.1	300.0
Leaching (electrowon)	144.5	147.7	^a 120.8	^a 104.6	100.0
Zimbabwe ^{a 7}	18.5	16.1	15.7	^a 14.7	14.5
Total^{a 13}	^a8,243.2	^a8,323.1	^a8,667.4	^a8,693.4	8,819.5

^aEstimated. ^aRevised.

¹Data represent copper content by analysis of concentrates produced except where otherwise noted. Table includes data available through June 30, 1992.

²Reported figure.

³Less than 50 tons.

⁴Copper content of pelletized nickel-copper matte produced in smelter.

⁵Reported by Comision Chilena del Cobre (COCHILCO). Includes recoverable copper content of nonduplicative mine and metal products produced from domestic ores and concentrates, and leach production for electrowinning. Mine production data reported by Servicio Nacional de Geologia y Minería (SERNAGEOMIN) were as follows, in thousand metric tons: 1987—1,412.9; 1988—1,472.0; 1989—1,628.3; 1990—1,616.3; and 1991—1,840.0 (estimated).

⁶Copper content of cement copper. Includes copper content of pyrite for 1989.

⁷Recoverable content.

⁸Recoverable copper content by analysis of concentrates for export plus nonduplicative total of copper content of all metal and metal products produced indigenously from domestic ores and concentrates; includes leach production for electrowinning in Portugal.

⁹Includes copper content of pyrite.

¹⁰Includes electrowon from concentrates roast-leached.

¹¹Copper content by analysis of ore mined.

¹²Data are for fiscal years beginning Apr. 1 of year stated. Zambian-mined copper reported recovered during smelting and electrowinning.

¹³Data may not add to totals shown because of independent rounding.

TABLE 31
COPPER: WORLD REFINERY PRODUCTION,¹ BY COUNTRY

(Thousand metric tons)

Country	1987	1988	1989	1990	1991*
Albania, primary	¹ 12.8	¹ 14.1	¹ 14.5	¹ 10.0	8.0
Argentina, secondary	13.0	12.5	11.0	¹ 15.0	² 15.0
Australia:					
Primary	178.9	¹ 196.0	210.0	247.0	² 252.0
Secondary	28.8	26.7	25.0	² 27.0	30.0
Total ³	207.8	² 222.7	235.0	² 274.0	282.0
Austria:					
Primary	3.9	3.6	7.2	⁸ 7.7	8.4
Secondary	32.9	38.4	39.1	⁴ 41.0	44.4
Total ³	36.8	41.9	46.3	49.7	52.8
Belgium: ⁴					
Primary	³ 315.5	² 299.9	² 256.0	² 259.0	185.0
Secondary	92.0	93.0	⁸ 88.0	102.0	102.0
Total	⁴ 407.5	³ 392.9	³ 344.0	³ 361.0	287.0
Brazil:					
Primary	147.0	147.9	153.4	¹ 140.0	140.0
Secondary	52.2	38.1	42.3	45.0	45.0
Total ³	199.2	185.9	195.6	¹ 185.0	185.0
Bulgaria: ⁵					
Primary	44.0	⁴ 45.5	45.8	² 14.3	14.0
Secondary	10.0	10.0	10.0	10.0	10.0
Total	54.0	⁵ 55.5	⁵ 55.8	² 24.3	24.0
Canada:					
Primary	⁴ 460.6	⁴ 482.1	⁴ 478.0	⁴ 471.9	497.0
Secondary	³ 30.6	⁴ 46.6	³ 37.8	⁴ 43.9	41.0
Total	491.2	528.7	⁵ 515.8	⁵ 515.8	538.0
Chile, primary	970.3	1,012.7	1,071.0	1,191.6	² 1,237.8
China, primary and secondary ⁶	400.0	510.0	540.0	560.0	560.0
Czechoslovakia:					
Primary ⁷	10.3	10.0	10.0	⁸ 8.0	2.5
Secondary ⁷	16.9	17.1	16.9	¹ 16.6	15.5
Total	27.2	27.1	26.9	² 24.6	18.0
Egypt, secondary	² 2.5	⁴ 4.0	³ 3.6	¹ 3.6	3.6
Finland:					
Primary	54.5	47.9	49.7	⁵ 57.1	56.5
Secondary ⁸	5.0	6.0	6.0	8.0	8.0
Total ⁸	59.5	53.9	55.7	⁶ 65.1	64.5
France:					
Primary	11.3	7.2	20.3	² 22.9	16.0
Secondary	28.0	36.0	29.0	² 29.0	30.0
Total	39.3	43.2	49.3	⁵ 51.9	46.0
Germany:					
Primary:					
Eastern states ⁹	⁶ 64.0	⁶ 61.0	⁶ 62.0	³ 39.9	NA
Western states	195.1	192.2	¹ 196.1	² 204.0	NA
Subtotal	259.1	253.2	258.1	243.9	306.5
Secondary:					
Eastern states ⁹	³ 31.0	³ 34.1	³ 31.6	¹ 16.8	NA
Western states	204.7	234.2	² 279.1	² 272.2	NA

See footnotes at end of table.

TABLE 31—Continued
COPPER: WORLD REFINERY PRODUCTION,¹ BY COUNTRY

(Thousand metric tons)

Country	1987	1988	1989	1990	1991 ^a
Subtotal	235.7	268.3	310.7	289.0	216.0
Total:					
Eastern states ^a	^r 95.0	^r 95.1	^r 93.6	^r 56.7	NA
Western states	399.8	426.4	475.2	476.2	NA
Total^a	494.8	521.5	568.8	532.9	²522.5
Hungary, primary and secondary ^a	12.5	19.2	19.0	^r 19.0	18.0
India, primary:					
Electrolytic	30.0	38.9	41.0	^r 40.6	² 45.0
Fire refined	.8	1.2	.8	^r 1.0	1.0
Total	30.8	40.1	41.8	^r41.6	46.0
Iran, primary: ^{a 3}	25.0	32.0	40.0	^r 43.3	77.9
Italy:					
Primary ^a	^r 7.6	^r 16.3	^r —	^r —	—
Secondary	^r 57.4	^r 59.1	^r 83.3	^r 83.0	82.5
Total	65.0	75.4	83.3	^r83.0	82.5
Japan:					
Primary	871.0	854.6	882.3	893.1	² 967.7
Secondary	109.4	100.5	107.3	114.8	² 108.6
Total³	980.3	955.1	989.6	1,008.0	²1,076.3
Korea, North: ^a					
Primary	18.0	18.0	18.0	18.0	20.0
Secondary	4.0	4.0	4.0	4.0	4.0
Total	22.0	22.0	22.0	22.0	24.0
Korea, Republic of:					
Primary	154.6	168.3	178.7	^r 183.0	184.0
Secondary	3.3	.7	1.2	^r 2.6	2.0
Total	157.9	169.0	179.9	185.6	186.0
Mexico:					
Primary:					
Electrowon	^r 8.7	11.4	10.3	^r 26.9	² 32.1
Other ^a	104.9	107.7	113.8	^r 104.7	105.0
Secondary ^a	21.2	21.8	23.0	^r 21.2	22.0
Total³	^r134.8	140.8	147.0	^r152.8	159.1
Norway, primary ³	29.4	31.7	35.0	36.5	² 38.4
Oman, primary	15.5	16.5	15.1	^r 12.1	12.0
Peru, primary	225.9	179.6	220.0	181.5	246.1
Philippines, primary	132.1	132.2	132.2	^r 125.5	120.0
Poland, primary ³	^r 390.2	^r 400.6	390.3	^r 352.0	² 378.0
Portugal, primary ^{a 3}	5.3	5.4	6.0	6.0	6.0
Romania: ^a					
Primary	^r 39.5	^r 40.0	^r 42.9	^r 24.7	20.0
Secondary	^r 3.0	^r 3.0	^r 5.0	^r 3.0	2.0
Total	^r42.5	^r43.0	^r48.0	^r27.7	22.0
South Africa, Republic of, primary ³	^r 146.5	^r 136.7	^r 144.2	^r 133.0	² 138.8
Spain:					
Primary	100.4	108.8	^r 115.7	^r 116.0	115.0
Secondary	51.0	50.0	^r 50.0	^r 50.0	50.0
Total	151.4	158.8	^r165.7	^r166.0	165.0

See footnotes at end table.

TABLE 31—Continued
COPPER: WORLD REFINERY PRODUCTION,¹ BY COUNTRY

(Thousand metric tons)

Country	1987	1988	1989	1990	1991 ^a
Sweden:					
Primary	79.9	68.3	70.0	¹ 66.3	66.1
Secondary	12.0	22.0	24.6	¹ 31.0	30.5
Total	91.9	90.3	94.6	97.3	96.6
Taiwan:					
Primary	47.0	43.3	43.2	16.1	—
Secondary ^a	10.0	10.0	10.0	¹ 6.0	12.0
Total ^a	57.0	53.3	53.3	² 22.1	12.0
Turkey, primary	75.6	90.0	¹ 86.4	¹ 84.2	85.0
U.S.S.R.:^a					
Primary	840.0	850.0	850.0	800.0	750.0
Secondary	147.0	150.0	150.0	130.0	120.0
Total	987.0	1,000.0	1,000.0	930.0	870.0
United Kingdom:					
Primary	54.0	49.3	48.6	47.0	17.1
Secondary	68.3	74.7	70.4	¹ 74.6	53.0
Total	122.3	124.0	119.0	¹ 121.6	70.1
United States:					
Primary:					
Electrowon	161.3	228.0	311.9	393.5	² 441.2
Other	965.6	1,178.0	1,164.9	1,183.2	² 1,136.2
Secondary	414.7	446.0	480.0	440.8	² 417.8
Total ³	1,541.6	1,852.0	1,956.8	2,017.4	² 1,995.2
Yugoslavia:					
Primary	98.8	105.6	¹ 101.9	¹ 102.2	100.0
Secondary	40.1	39.8	¹ 49.2	¹ 49.2	22.2
Total ³	138.9	145.4	151.0	151.4	122.2
Zaire, primary⁶	210.1	202.6	181.9	² 201.3	140.0
Zambia, primary:⁷					
Electrowon	69.6	51.8	45.4	¹ 52.7	50.0
Other	426.6	397.7	418.1	¹ 385.4	380.0
Total ³	496.3	449.6	463.6	¹ 438.1	430.0
Zimbabwe:⁸					
Primary	18.8	16.1	15.7	¹ 14.1	14.0
Secondary ^a	4.2	11.4	8.3	8.4	8.2
Total ^a	23.0	27.5	24.0	² 22.5	22.2
Grand total³	9,726.7	10,219.4	10,542.9	10,545.8	10,483.6
Of which:					
Primary ³	¹ 7,820.9	¹ 7,942.5	¹ 8,133.7	¹ 8,130.9	8,410.4
Secondary ³	¹ 1,493.2	¹ 1,747.6	¹ 1,850.2	¹ 1,835.9	1,493.3
Primary and secondary, undifferentiated	412.5	529.2	559.0	579.0	578.0

^aEstimated. ^bRevised.

¹This table includes total production of refined copper, whether produced by pyrometallurgical or electrolytic refining methods and whether derived from primary unrefined copper or from scrap. Copper cathode derived from electrowinning processing is also included. Table includes data available through June 30, 1992.

²Reported figure.

³Data may not add to totals shown because of independent rounding.

⁴Includes leach cathode from Zaire, which is processed.

⁵May include secondary.

⁶Excludes leach cathode exported for reprocessing in Belgium.

⁷Data are for fiscal year beginning Apr. 1 of that stated. Electrowon covers only presumably high-grade cathodes reported as "finished production leach cathodes." Other, in addition to electrorefined cathodes, includes a smaller amount of "finished product shapes" presumably cast from electrorefined cathodes, high-grade electrowon cathodes, or any blister-anodes and low-grade electrowon cathodes that were furnace- or fire-refined.

⁸May not include copper-nickel matte (copper content more than 6,000 tons per year) imported from Botswana for toll refining.

TABLE 32
COPPER: WORLD SMELTER PRODUCTION,¹ BY COUNTRY

(Thousand metric tons)

Country ² and metal origin	1987	1988	1989	1990	1991 ^a
Albania, primary	¹ 13.9	¹ 14.8	¹ 15.3	¹ 12.0	6.0
Australia:					
Primary	172.9	177.8	² 204.0	192.0	³ 197.0
Secondary	⁸ 8.5	10.5	¹ 10.0	¹ 10.0	10.0
Total	¹ 181.4	188.3	¹ 214.0	² 202.0	207.0
Austria, secondary	29.1	34.5	39.1	⁴ 41.0	44.8
Belgium: ^o					
Primary	.1	.2	.2	.2	.2
Secondary	92.2	93.2	93.4	94.0	100.0
Total	92.1	93.4	93.6	94.2	100.2
Brazil, primary	147.0	147.9	153.4	¹ 157.1	160.0
Bulgaria: ^o					
Primary	⁵ 2.0	⁵ 4.0	⁵ 5.0	² 9.0	29.0
Secondary	3.0	3.0	2.0	1.6	1.0
Total	⁵ 5.0	⁵ 7.0	¹ 57.0	³ 0.0	30.0
Canada:					
Primary	⁴ 74.0	⁴ 78.3	⁴ 62.3	⁴ 81.3	532.8
Secondary	³ 0.6	⁴ 6.6	³ 7.8	⁴ 3.9	42.0
Total	⁵ 04.6	⁵ 24.9	⁵ 00.1	⁵ 25.2	574.8
Chile, primary ⁴	1,106.9	1,189.4	1,226.6	¹ ,328.5	¹ ,296.1
China, primary ^o	300.0	³ 20.0	³ 40.0	³ 50.0	360.0
Czechoslovakia:					
Primary ^o	5.3	5.0	⁵ 5.5	⁴ 4.3	2.5
Secondary ^o	21.9	22.1	² 1.4	² 0.3	15.5
Total	27.2	27.1	² 6.9	² 4.6	18.0
Finland:					
Primary	77.4	79.0	79.5	⁹ 0.2	90.1
Secondary ^o	12.0	12.0	12.0	12.0	12.0
Total ^o	89.4	91.0	91.5	102.2	102.1
France, secondary	7.0	8.5	⁸ 4	⁹ 0	9.0
Germany:					
Primary:					
Eastern states ^o	17.0	25.0	25.0	20.0	NA
Western states	165.0	171.5	180.0	¹ 73.6	NA
Total primary	182.0	196.5	205.0	193.6	191.2
Secondary:					
Eastern states ^o	47.0	36.0	37.0	19.9	NA
Western states	42.7	50.0	75.9	75.9	NA
Total secondary	89.7	86.0	112.9	95.8	82.0
Total	271.7	282.5	317.9	289.4	273.2
Hungary, secondary ^o	.1	.1	.1	.1	.1
India, primary	32.9	44.3	42.5	⁴ 0.7	42.0
Iran: ^{o 5}					
Primary	38.0	49.4	72.2	⁵ 2.1	52.4
Secondary	2.0	2.6	3.8	² 7	2.8
Total	40.0	52.0	76.0	54.8	55.2
Japan:					
Primary	871.0	854.6	882.3	893.2	⁹ 67.7
Secondary	109.0	139.4	123.2	¹ 47.4	124.3

See footnotes at end of table.

TABLE 32—Continued
COPPER: WORLD SMELTER PRODUCTION, BY COUNTRY

(Thousand metric tons)

Country ² and metal origin	1987	1988	1989	1990	1991*
Total	980.0	994.0	¹1,005.5	1,040.6	1,092.0
Korea, North:³					
Primary	15.0	15.0	15.0	15.0	20.0
Secondary	3.0	3.0	3.0	3.0	5.0
Total	18.0	18.0	18.0	18.0	25.0
Korea, Republic of, primary	143.8	123.5	123.6	¹124.0	125.0
Mexico, primary	126.3	150.3	174.3	¹175.4	175.0
Namibia, primary	³37.7	⁴42.2	38.0	³32.7	³32.9
Norway, primary	29.7	31.7	35.0	36.5	³38.4
Oman, primary	15.7	16.8	¹15.2	¹12.1	³11.4
Peru, primary	323.0	246.9	²241.2	¹195.5	³268.8
Philippines, primary	124.7	¹159.2	105.0	¹110.0	105.0
Poland:⁵					
Primary	385.0	385.0	380.0	³ 326.0	360.0
Secondary	25.0	25.0	20.0	20.0	20.0
Total	410.0	410.0	400.0	³346.0	380.0
Portugal:⁶					
Primary	2.0	2.5	.7	1.0	1.0
Secondary	2.0	2.0	2.0	2.0	2.0
Total	4.0	4.5	2.7	3.0	3.0
Romania:⁷					
Primary	30.0	28.0	42.0	² 28.3	25.0
Secondary	8.0	8.0	8.0	¹ 1.0	1.0
Total	38.0	36.0	50.0	²29.3	26.0
South Africa, Republic of, primary	¹186.8	¹180.6	¹184.8	¹176.0	170.4
Spain:					
Primary	115.7	111.0	120.0	¹ 110.0	115.0
Secondary	33.0	34.6	32.3	³ 32.0	34.0
Total	148.7	145.6	152.3	¹142.0	149.0
Sweden:					
Primary	92.9	93.7	87.1	84.2	84.0
Secondary	12.7	22.2	24.6	23.8	24.0
Total	105.6	115.9	111.7	108.0	108.0
Taiwan, primary	47.0	43.3	43.2	16.1	—
Turkey:					
Primary	19.1	¹ 12.8	² 20.9	¹ 19.7	¹ 19.7
Secondary	¹ .1	¹ .1	² .2	² .2	.2
Total	¹19.2	12.9	21.1	¹19.9	19.9
U.S.S.R.:⁸					
Primary	790.0	800.0	800.0	750.0	700.0
Secondary	147.0	150.0	150.0	130.0	120.0
Total	937.0	950.0	950.0	880.0	820.0
United States:					
Primary ⁶	972.1	1,043.0	1,120.4	1,158.5	¹ 1,123.0
Secondary	276.6	331.6	359.1	304.8	³ 364.3
Total	1,248.7	1,374.6	1,479.5	1,463.3	¹1,487.3

See footnotes at end of table.

TABLE 32—Continued
COPPER: WORLD SMELTER PRODUCTION,¹ BY COUNTRY

(Thousand metric tons)

Country ² and metal origin	1987	1988	1989	1990	1991 ^a
Yugoslavia:					
Primary	103.4	106.5	¹ 101.6	¹ 105.9	95.0
Secondary	62.4	65.5	¹ 71.4	¹ 68.3	30.0
Total	165.8	172.0	173.0	¹ 174.3	125.0
Zaire, primary:					
Electrowon ^b	³ 307.5	³ 306.3	³ 300.4	² 201.3	150.0
Other ^c	³ 179.9	160.0	150.0	³ 138.0	80.0
Total	487.4	⁴ 466.3	⁴ 450.4	³ 339.4	230.0
Zambia, primary:⁷					
Electrowon	74.8	95.9	⁷ 75.4	⁵ 51.9	50.0
Other	347.9	308.9	³ 345.5	³ 316.3	315.0
Total	⁴ 422.7	404.8	⁴ 420.8	³ 368.2	365.0
Zimbabwe, primary⁸	18.8	16.1	15.7	¹ 16.2	16.2
Grand total⁹	⁸ 9,936.9	⁹ 9,190.7	⁹ 9,413.4	⁹ 9,087.1	9,051.8
Of which:					
Primary:					
Electrowon	382.3	⁴ 402.2	³ 375.8	² 253.2	200.0
Other	⁷ 7,579.9	⁷ 7,688.1	⁷ 7,902.9	⁷ 7,771.6	7,807.8
Secondary	⁹ 974.8	¹ 1,100.5	¹ 1,134.7	¹ 1,062.3	1,044.0

^aEstimated. ^bRevised. NA Not available.

¹This table includes total production of copper metal at the unrefined stage, including low-grade cathode produced by electrowinning methods. The smelter feed may be derived from ore, concentrates, copper precipitate or matte (primary), and/or scrap (secondary). To the extent possible, primary and secondary output of each country is shown separately. In some cases, total smelter production is officially reported, but the distribution between primary and secondary has been estimated. Table includes data available through June 30, 1992.

²Argentina presumably produces some smelter copper utilizing its own small mine output together with domestically produced cement copper, and possibly using other raw materials, including scrap, but the levels of such output cannot be reliably estimated.

³Reported figure.

⁴Data include electrowon production; estimated to be 35,000 to 45,000 tons per year that is fire-refined and cast into wirebars; detailed data are not available.

⁵Data may be for year beginning Mar. 21 of year stated. Only estimated production data are available. Secondary production is estimated to be about 5% of total.

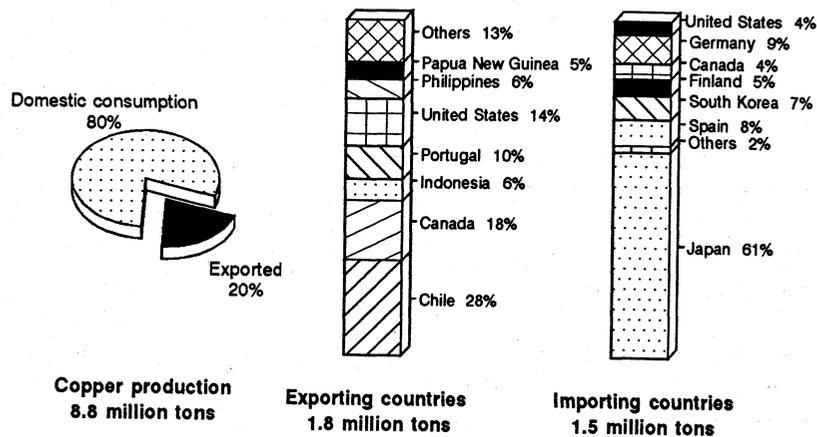
⁶Figures for U.S. primary smelter production may include a small amount of copper derived from precipitates shipped directly to the smelter for further processing; production derived from electrowinning and fire-refining is not included. Copper content of precipitates shipped directly to smelter are as follows, in metric tons: 1987—70,136; 1988—49,299; 1989—34,485; 1990—19,817; and 1991—24,954.

⁷For fiscal year beginning Apr. 1 of year stated. Electrowon is total electrowon production reported, less the quantity reported as "finished production, leach cathodes." (See table 38).

⁸Refined figure; unrefined data not available. Includes production from low-grade electrowon cathodes produced in nickel processing.

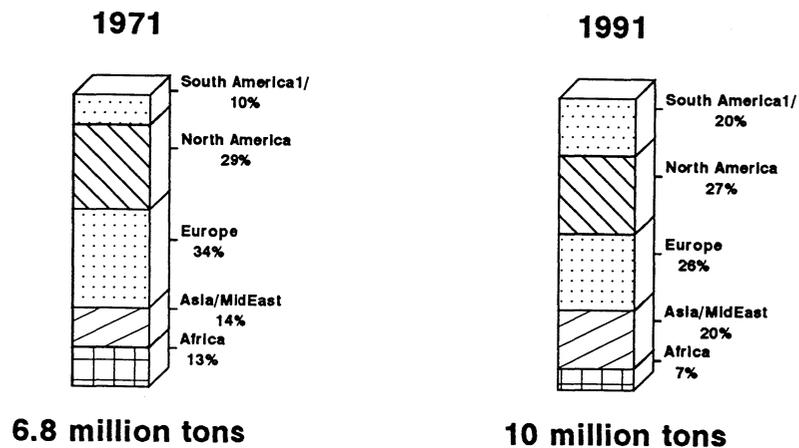
⁹Totals may not add to detail shown because of independent rounding.

FIGURE 1
WORLD COPPER MINE PRODUCTION AND CONCENTRATE
IMPORTING AND EXPORTING COUNTRIES IN 1991



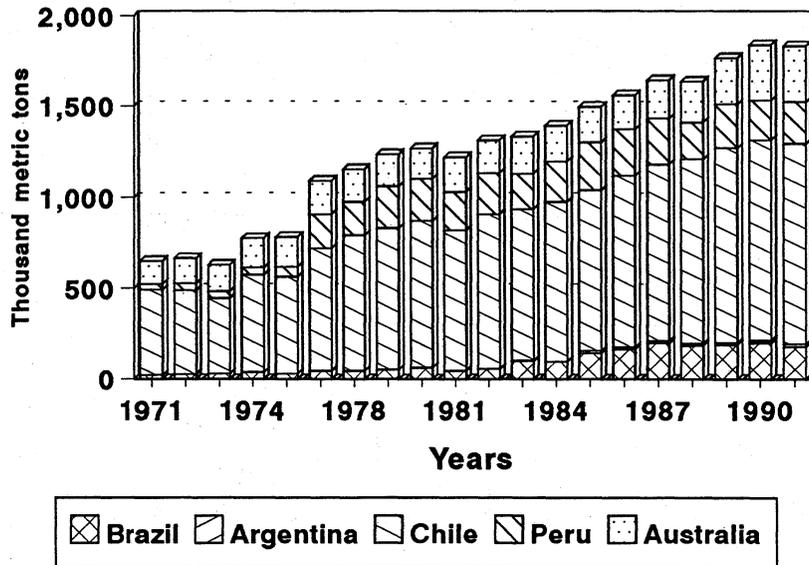
Sources: U.S. Bureau of Mines and World Bureau of Metal Statistics.

FIGURE 2
WORLD REFINED COPPER PRODUCTION
(Metric tons)



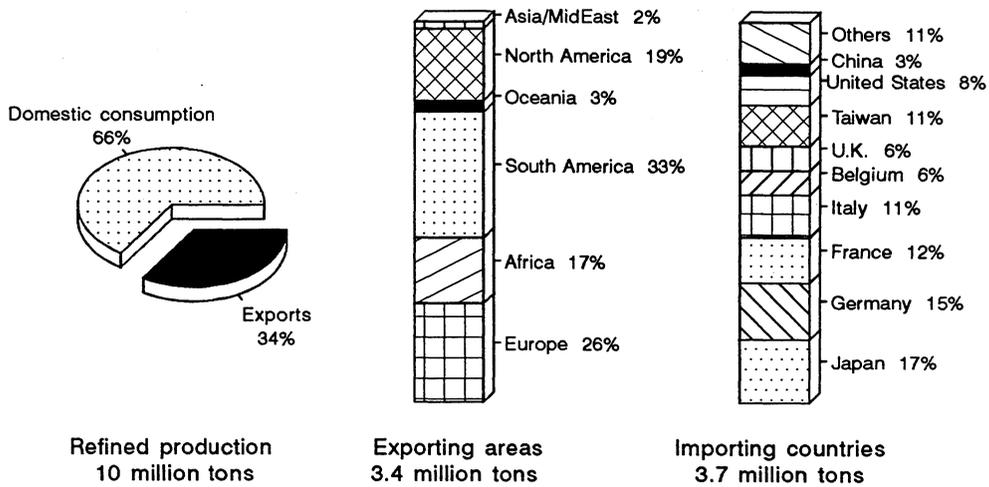
¹/South America includes Australia.
 Source: U.S. Bureau of Mines, Aug. 1992.

FIGURE 3
REFINED COPPER PRODUCTION IN SOUTH AMERICA AND AUSTRALIA



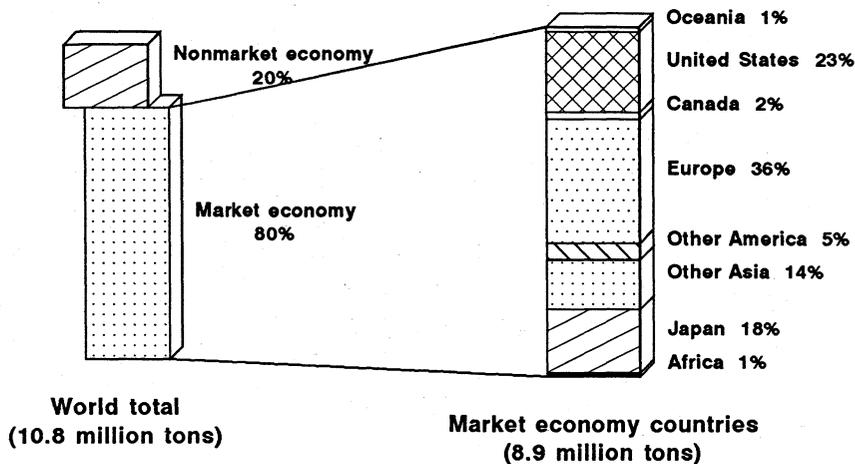
Source: U.S. Bureau of Mines, Aug. 1992.

FIGURE 4
WORLD REFINED COPPER PRODUCTION, EXPORTS AND IMPORTS IN 1991



Sources: U.S Bureau of Mines and World Bureau of Metal Statistics.

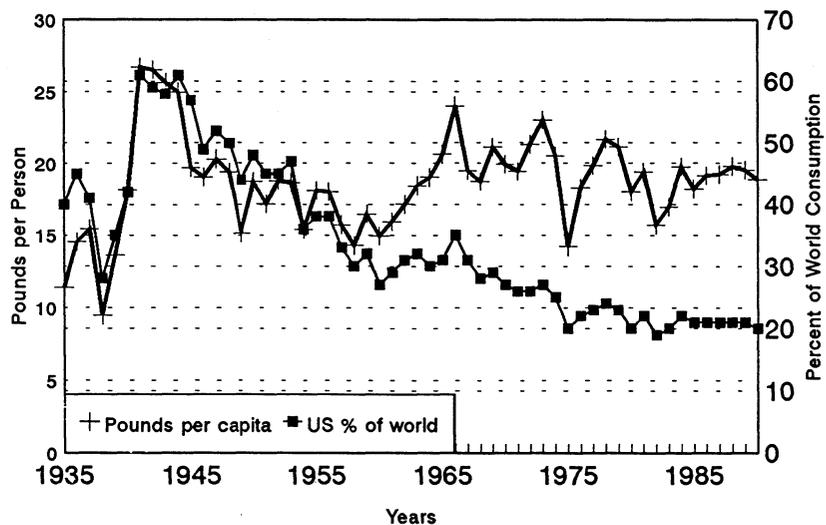
FIGURE 5
WORLD COPPER CONSUMPTION IN 1991



Sources: U.S. Bureau of Mines and World Bureau of Metal Statistics, Aug. 1992.

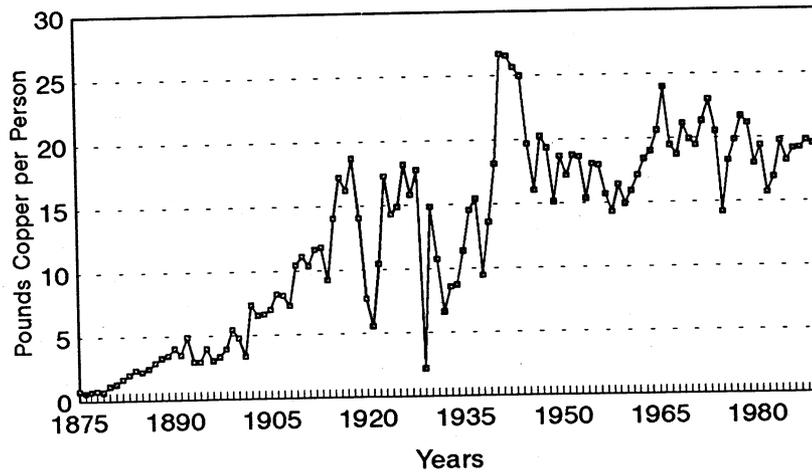
FIGURE 6
U.S. COPPER CONSUMPTION TRENDS

(Percent of World and Pounds per Capita)



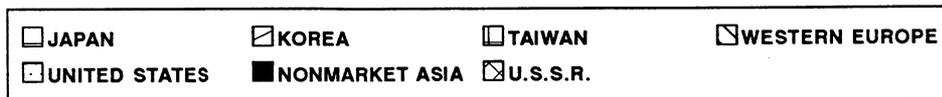
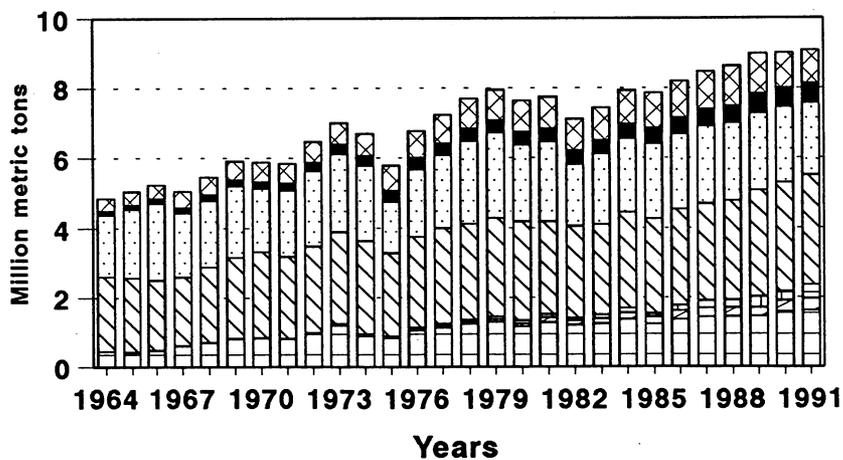
1/Consumption by brass mills, wire-rod mills, foundries, chemical plants and miscellaneous semifabricators.
 Sources: U.S. Bureau of Mines and Bureau of Census.

FIGURE 7
PER CAPITA COPPER CONSUMPTION IN THE UNITED STATES



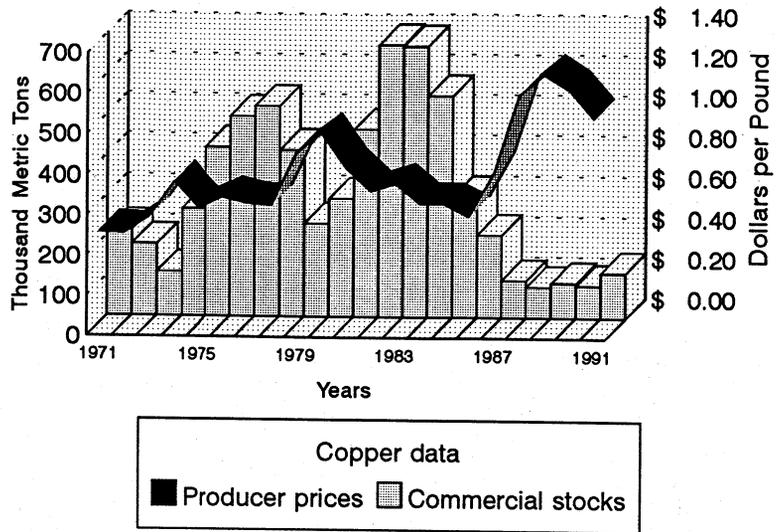
1/Consumption by brass mills, wire-rod mills, foundries, chemical plants, and miscellaneous semifabricators.
Sources: U.S. Bureau of Mines and Bureau of the Census.

FIGURE 8
REFINED COPPER CONSUMPTION IN PRINCIPAL COUNTRIES OR AREAS



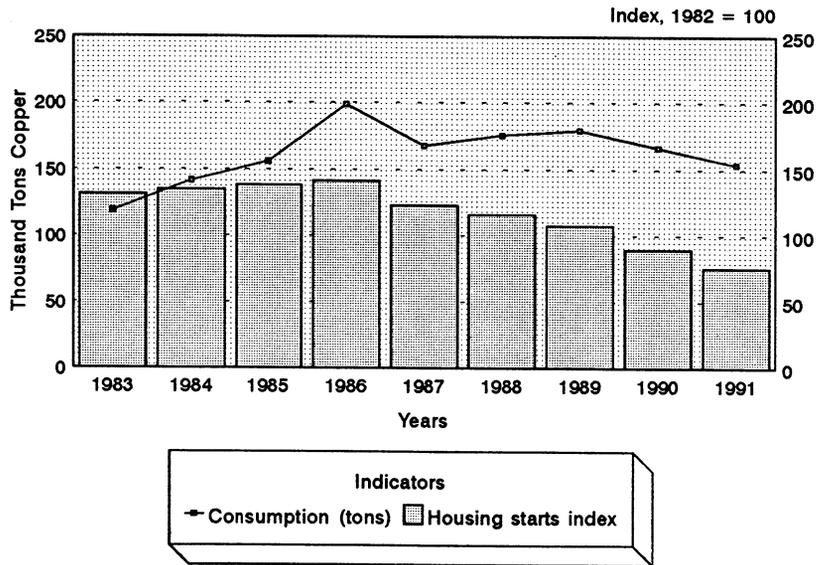
Sources: Bureau of Mines and World Bureau of Metal Statistics, Aug. 1992.

FIGURE 9
COMPARISON OF U.S. REFINED COPPER PRICES AND COMMERCIAL INVENTORIES



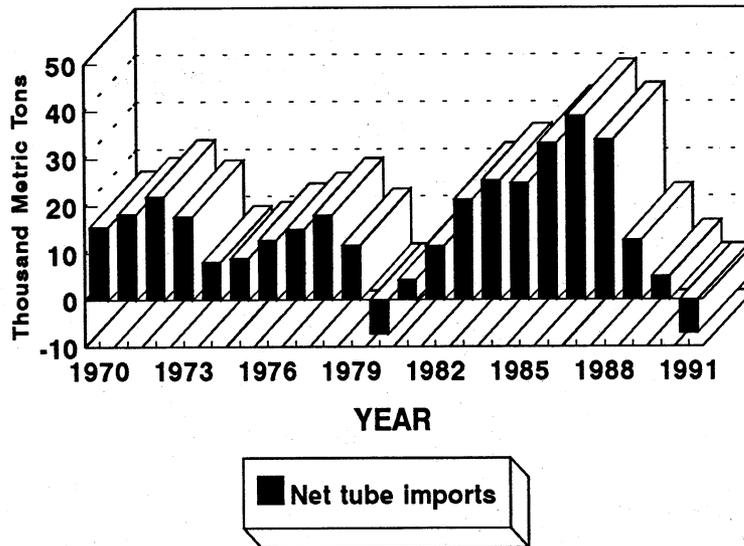
Sources: Metals Week (prices), COMEX, U.S. Bureau of Mines, Aug. 1992.

FIGURE 10
COMPARISON OF HOUSING STARTS AND COPPER CONSUMPTION BY U.S. COPPER TUBE FABRICATORS



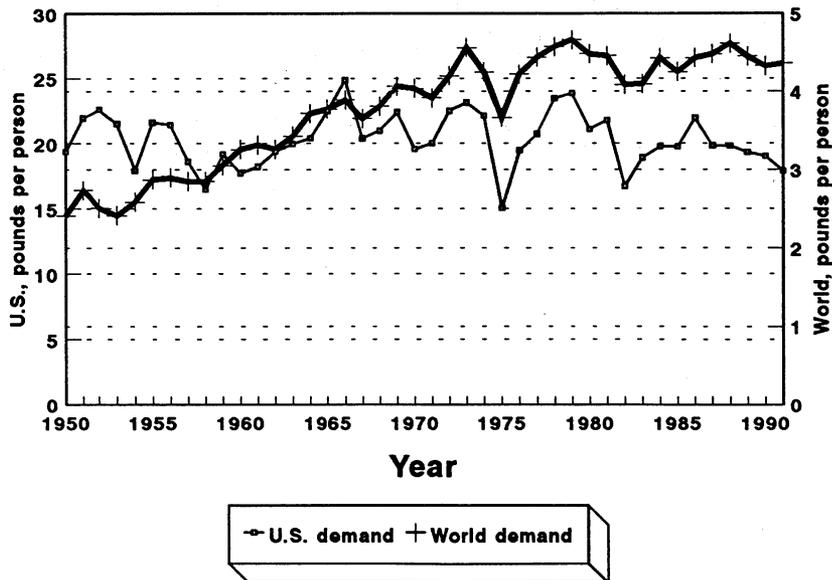
Sources: U.S. Bureau of Mines, Bureau of the Census, Aug. 1992.

FIGURE 11
TRENDS IN NET U.S. IMPORTS OF COPPER TUBE AND PIPE



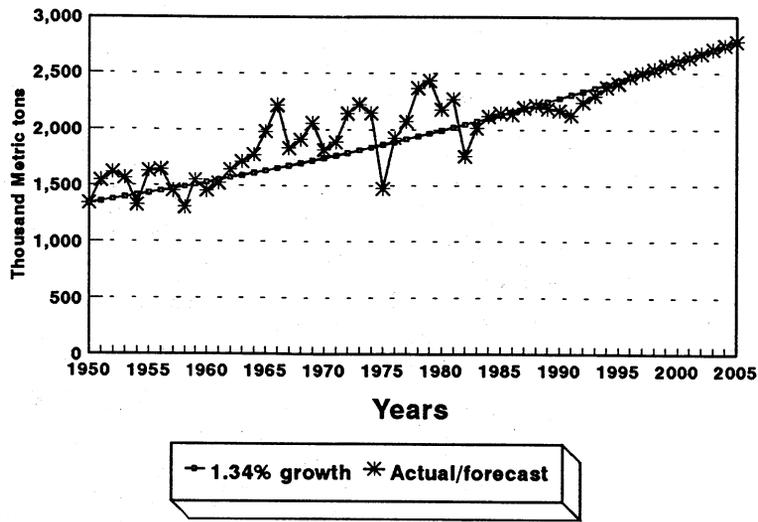
Sources: Copper & Brass Fabricators Council, Inc. and Bureau of the Census.

FIGURE 12
WORLD AND U.S. PER CAPITA DEMAND



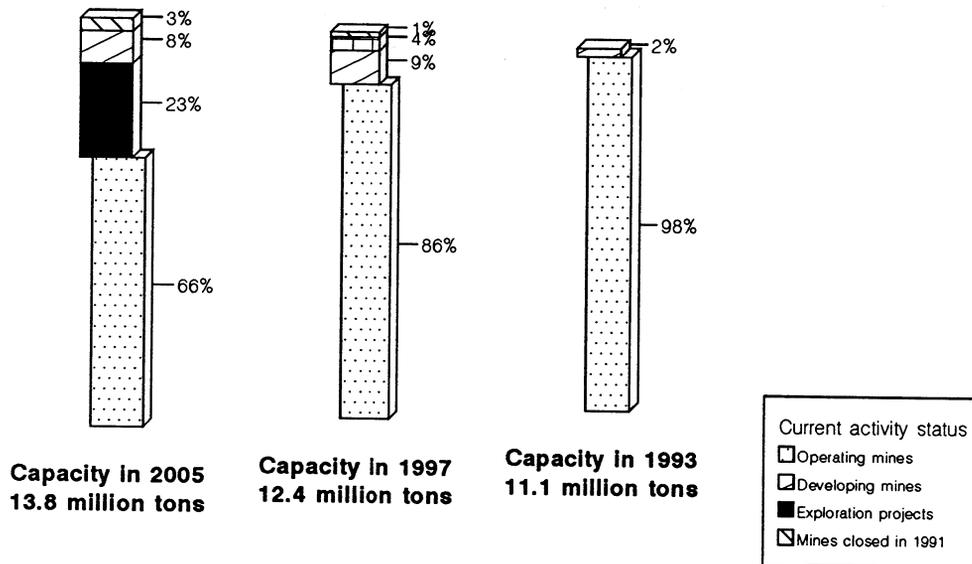
Sources: U.S. Bureau of Mines and Bureau of the Census, Sept. 1992.

FIGURE 13
U.S. COPPER CONSUMPTION TREND AND FORECAST



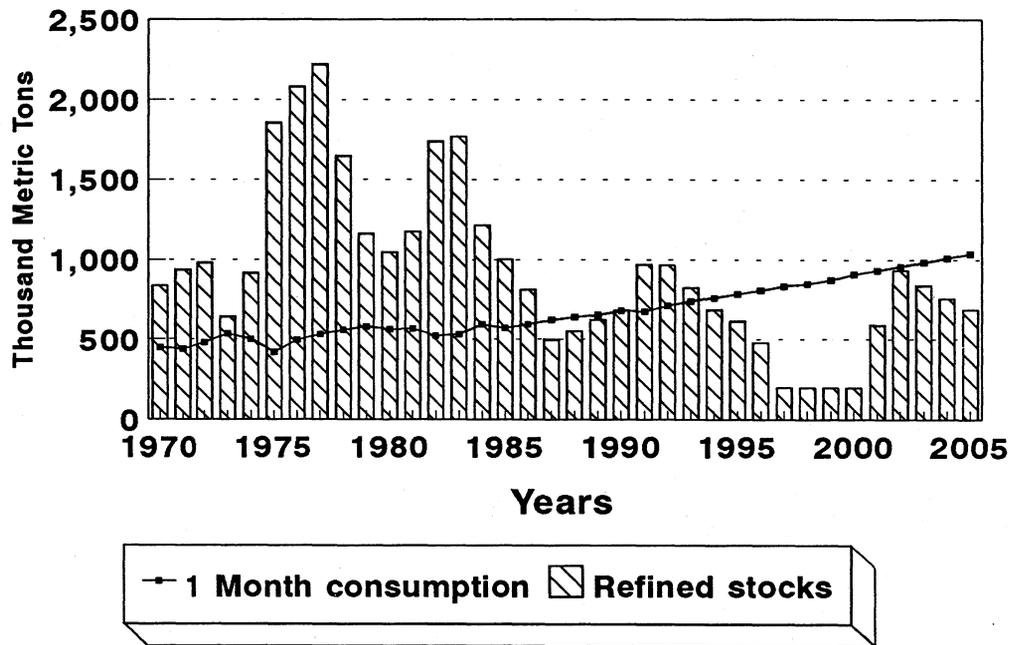
Source: U.S. Bureau of Mines, Sept. 1992.

FIGURE 14
FORECAST WORLD COPPER MINE CAPACITY, BY CURRENT ACTIVITY STATUS
 (Percent of World Total)



Source: U.S. Bureau of Mines, Aug. 1992.

FIGURE 15
 MARKET ECONOMY REFINED COPPER STOCKS AND 1 MONTH'S AVERAGE CONSUMPTION



Source: U.S. Bureau of Mines, Sept. 1992.

DIATOMITE

By Lawrence L. Davis

Mr. Davis, a physical scientist with 36 years of industry and U.S. Bureau of Mines experience, has been the acting commodity specialist for diatomite since 1989. Domestic survey data were prepared by Tonya Hardin, statistical assistant; and international data tables were prepared by Audrey Wilkes, international data coordinator.

U.S. sales of processed diatomite decreased 3% to 610,000 metric tons, valued at \$140 million, according to the U.S. Bureau of Mines, U.S. Department of the Interior. The major use of diatomite was in filtration to separate suspended solids in liquids.

DOMESTIC DATA COVERAGE

Diatomite production data were collected from voluntary surveys of all 11 known operations. All responded, representing 100% of the production data shown in table 1.

ANNUAL REVIEW

Production

Five companies processed diatomite at 11 plants in 4 States. California continued to be the leading State, followed by Nevada, Oregon, and Washington. Major domestic producers were Celite Corp., with operations at Lompoc, CA, and Quincy, WA; Grefco Inc., Dicalite Div., at Lompoc and Burney, CA, and Mina, NV; and Eagle-Picher Minerals Inc. at Sparks and Lovelock, NV, and Vale, OR. Other producers were CR Minerals Corp., Fernley, NV; and Oil-Dri Production Co., Christmas Valley, OR. During 1991, Manville sold its Celite operation at Lompoc, CA, to Alleghany Corp. Celite also purchased the Inorganic Specialties Div. of Witco Corp., which

operates a diatomite mine and plant at Quincy, WA.

Consumption

Apparent domestic consumption of processed diatomite decreased 6% to 458,000 metric tons. In 1991, domestic and export sales of filter-grade diatomite were 441,000 metric tons, 2% less than that of 1990. Sales of diatomite as a filler, the second largest use, were about 83,000 metric tons, a decrease of 8% from that of 1990.

Markets and Prices

The average unit value of sales for processed diatomite was \$229 per metric ton, 5% above that in 1990. U.S. exports of processed diatomite were 152,000 metric tons, about 6% more than in 1990. The average unit value was \$297 per metric ton compared with \$293 per metric ton in 1990. Diatomite was exported to 72 countries. Canada, 21,900 metric tons; Japan, 17,700 metric tons; France, 14,300 metric tons; the Federal Republic of Germany, 13,800 metric tons; and Australia, 11,200 metric tons; combined received 52% of the total exported. U.S. exports represented 25% of domestic production. Imports of diatomite were 436 metric tons, of which 86% was supplied by Mexico.

World Review

World production was estimated to be 1.6 million metric tons in 1991. The

United States remained the world's leading producer, followed by France, the U.S.S.R., and Spain. These four countries accounted for 75% of world production.

OUTLOOK

Diatomite consumption is expected to increase slightly over the next few years. Filtration will continue to be the major end use.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Diatomite. Ch. in Minerals Yearbook, annual.
Diatomite, Ch. in Mineral Commodity Summaries, annual.

Diatomite. Ch. in Bulletin 675, Mineral Facts and Problems, 1985 edition.

Other Sources

Engineering and Mining Journal.
Mining Engineering.
Mining Journal.

TABLE 1
DIATOMITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES

(Thousand metric tons and thousand dollars)

	1987	1988	1989	1990	1991
Domestic production (sales)	596	629	617	631	610
Total value of sales	\$134,239	\$143,774	\$136,754	\$137,982	\$139,857

TABLE 2
DIATOMITE SOLD OR USED,¹ BY MAJOR USE

(Percent of U.S. production)

Use	1987	1988	1989	1990	1991
Fillers	16	17	15	14	14
Filtration	69	69	71	71	72
Insulation	2	2	3	4	4
Other ²	13	12	11	11	10

¹Includes exports.

²Includes absorbents, additives, and silicate admixtures.

TABLE 3
AVERAGE ANNUAL VALUE PER METRIC TON¹ OF DIATOMITE, BY MAJOR USE

Use	1989	1990	1991
Fillers	\$233.68	\$237.06	\$246.87
Filtration	237.61	233.68	221.28
Insulation	107.61	112.67	119.65
Other ²	132.89	130.23	135.07
Weighted average	221.58	218.65	229.40

¹Based on unrounded data.

²Includes absorbents, additives, and silicate admixtures.

TABLE 4
U.S. EXPORTS OF DIATOMITE

(Thousand metric tons and thousand dollars)

Year	Quantity	Value ¹
1988	147	39,374
1989	137	41,290
1990	144	42,329
1991	152	45,187

¹U.S. Customs.

TABLE 5
DIATOMITE: WORLD PRODUCTION, BY COUNTRY¹

(Thousand metric tons)

Country	1987	1988	1989	1990	1991 ^a
Algeria	³	³	⁴	⁴	4
Argentina	5	7	⁶	⁷	7
Australia	10	11	¹²	¹⁰	11
Brazil (marketable)	¹⁷	²⁴	²⁰	²⁰	20
Canada ^a	4	4	4	4	4
Chile	3	3	3	⁴	4
Colombia	3	3	4	4	4
Costa Rica ^a	⁵	⁵	5	5	5
Denmark: ^{a 2}					
Diatomite	6	6	6	1	1
Moler	66	66	70	60	60
France ^a	250	250	250	250	250
Germany, Federal Republic of: Western states	47	47	47	⁵⁰	50
Iceland	²³	25	²⁵	²⁶	22
Italy ^a	27	28	25	25	23
Kenya	1	1	1	¹	1
Korea, Republic of	65	72	75	⁵⁵	55
Mexico	35	37	45	⁵⁵	55
Peru	21	³⁰	²⁰	²⁰	20
Portugal	3	2	3	²	2
Romania ^a	⁵⁵	⁵⁵	⁵⁰	⁵⁰	40
South Africa, Republic of	(¹)	(¹)	(¹)	³	1
Spain ^a	100	100	100	⁸¹	80
Thailand	(¹)	(¹)	1	⁵	5
Turkey	5	—	—	—	—
U.S.S.R. ^a	255	260	260	250	220
United Kingdom	(¹)				
United States ⁴	597	629	617	631	⁶¹⁰
Yugoslavia	5	5	6	6	4
Total ⁶	^{1,611}	^{1,672}	^{1,660}	^{1,629}	1,556

^aEstimated. ^bRevised.

¹Table includes data available through Apr. 10, 1992.

²Data represent sales.

³Less than 1/2 unit.

⁴Sold or used by producers.

⁵Reported figure.

⁶Data may not add totals shown because of independent rounding.

FELDSPAR, NEPHELINE SYENITE, AND APLITE

By Michael J. Potter

Mr. Potter, a physical scientist, has been the commodity specialist for feldspar since 1976. Domestic survey data were prepared by Linder Roberts, statistical assistant; and the international data table was prepared by Virginia Woodson, international data coordinator.

Feldspars are major components in most igneous rocks and constitute a large part of at least the outer layers of the Earth and its moon. Feldspar, usually of the potash or soda type or in mixtures of the two, finds its principal end uses in the manufacture of glass and ceramics. In glass, feldspar is a source of alumina, which increases resistance to scratching and breaking and increases chemical stability. In ceramics, feldspar acts as a flux and lowers the melting temperature of a ceramic mixture.

Feldspar output decreased in 1991 compared with that of the previous year. Feldspar use in glass containers has been affected by competition from imported nepheline syenite, metal cans, plastic containers, and recycled glass cullet. A sluggish economy and fewer housing starts resulted in less feldspar demand in plumbing fixtures and tile. Imports of feldspar and nepheline syenite increased in 1991.

Studies were being made by the U.S. Department of Commerce and the U.S. International Trade Commission to determine whether imported nepheline syenite from Canada was being sold at less-than-fair value and if an industry in the United States was being materially injured or threatened with material injury.

DOMESTIC DATA COVERAGE

Domestic production data for feldspar are developed by the U.S. Bureau of Mines by means of a voluntary survey. Of the 12 active mill operations, 9 responded, representing 75% of the total

canvassed. These nine respondents reported a production of 475,000 metric tons or about 82% of the total domestic production shown in table 1. The estimated production of nonrespondents, 105,000 tons, was derived from past years' production levels and trends.

BACKGROUND

Definitions, Grades, and Specifications

Feldspar is the general term used to designate a group of closely related minerals, especially abundant in igneous rocks and consisting essentially of aluminum silicates in combination with varying proportions of potassium, sodium, and calcium. Principal feldspar types are orthoclase or microcline, both $K_2O \cdot Al_2O_3 \cdot 6SiO_2$, and anorthite, $CaO \cdot Al_2O_3 \cdot 2SiO_2$. Specimens of feldspar closely approaching these ideal compositions are seldom encountered in nature, however, and nearly all potash feldspars contain significant proportions of soda feldspar. Albite, or soda feldspar, and anorthite are the theoretical end members of a continuous compositional series known as the plagioclase feldspars, none of which is ordinarily without at least a minor admixture of potash. Commercially speaking, "potash spar" is feldspar containing 10% or more K_2O ; "soda spar" contains 7% or more Na_2O .

Perthite is the name given to material consisting of orthoclase or microcline and containing crystals that are intergrown

with crystals of albite. Most commercial feldspar can be classified most correctly as perthite.

In the feldspar industry, alaskite is a relatively coarse-grained, granitelike rock used as a feldspar ore from the Spruce Pine district of North Carolina. The principal mineral ingredients of this ore are approximately 45% plagioclase, 25% quartz, 20% microcline, and 10% muscovite mica. Minor amounts of other minerals are also present.¹ Beneficiated feldspar from alaskite is a major portion of total U.S. feldspar output.

Feldspar for glass manufacturing, ordinarily ground to 20 to 40 mesh, usually contains 4% to 6% K_2O , 5% to 7% Na_2O , and approximately 19% Al_2O_3 . Material for this purpose may be sold as a feldspar concentrate low in free quartz or in the form of a mixture containing feldspar and quartz with harmful impurities removed. In glass-grade feldspar, the iron content, expressed as Fe_2O_3 , should not exceed 0.10% for clear glass. Typically, 70 to 90 kilograms of ground feldspar is used to produce 1 ton of container glass.

Feldspar with a high potash-to-soda ratio is often preferred for pottery-making and is usually ground to minus 200 mesh. Potash spar ground to 120 or 140 mesh is usually specified for use in porcelain enamel, and even traces of such impurities as garnet, hornblende, tourmaline, and biotite mica ordinarily are not tolerated. Both potash and soda feldspars, ground to minus 200 mesh, are used in glazing.

Pottery-grade feldspar for whiteware and similar ceramic products may range from 5% to 14% in K_2O content and usually is ground to 200 mesh or finer. Limitations on iron content may be even more stringent than for glass grade; Fe_2O_3 content may not exceed 0.08% for many uses. Feldspar for use in filler applications, such as for foam rubber products, may be similar to pottery spar in fineness of grind and chemical composition, although more free quartz is often accepted; sometimes material for this purpose may be held to particle-size specifications expressed in micrometers.

Uses

The effects of feldspar on commercial glass batches include increased resistance to scratching and breaking and improved thermal endurance.² Processed feldspar is added to glassmaking formulas for its alumina and alkali contents. Alumina enhances the workability of molten glass and improves the finished product by giving it better chemical stability. The increased workability facilitates the operation of automatic machines for shaping jars and bottles. Greater chemical stability broadens the usefulness of the containers. Feldspar is used in ceramic mixtures, such as those for the making of vitreous china and porcelain enamels, principally as a flux. It fuses at a temperature below the melting point of most of the other ingredients. It also performs as a vitreous binder to cement particles of various crystalline substances present in ceramic mixtures. Feldspar serves advantageously in abrasives and scouring soaps. It forms a mild abrasive but is soft enough to avoid injury to the article being cleaned. Feldspar is also used as a filler in paint, foam rubber, and plastics.

Geology-Resources

Feldspar, one of the most abundant minerals in the Earth's crust, is found in significant amounts in some sedimentary strata and in nearly all igneous formations. Workable deposits of feldspar are probably widely distributed

throughout most of the world, and the total quantity of the mineral potentially available is very large.

It has been estimated that feldspar constitutes 60% of all crystalline igneous rocks. Granted sufficient demand and economic incentive, the mineral could be extracted from the world's granite, a source that is extremely large.

Data are not available on the quantity of feldspar in either domestic or foreign deposits. However, U.S. reserves are estimated to be quite large in the Spruce Pine district of North Carolina alone.

Feldspar concentrations of potential economic interest exist in many pegmatites, granites, and other granitic rocks and as accumulations of certain residual sands on ocean beaches or river banks.

Pegmatites are masses of coarsely crystalline rocks of igneous origin. Pegmatite bodies may range in size from small pods to extensive formations measuring hundreds or even thousands of meters. The principal feldspar ore bodies of pegmatitic type currently being exploited in the United States are in Connecticut, Georgia, North Carolina, and South Dakota. Potentially exploitable pegmatite bodies are known to exist in other areas.

The only feldspathic sand deposits being mined in the United States are in California, Idaho, and Oklahoma. Other accumulations of feldspathic sands in the United States offer possibilities as future sources of feldspar supply.

Granites are widely distributed igneous rocks of plutonic origin. Granites are present as major components of whole mountain ranges, and the dimensions of granite bodies can often be stated in kilometers. The important constituent minerals in granites are much the same as those in pegmatites, although there are likely to be significant differences in the respective proportions. Because of economic and technologic considerations, commercial utilization of granite in the United States as a source of feldspar is not presently taking place.

Technology

Most feldspathic rocks can be quarried by open pit procedures. High-grade, selectively mined feldspar from pegmatites may be dry processed, passing consecutively through jaw crushers, rolls, and pebble mills before being subjected to high-intensity magnetic or electrostatic treatment to bring the iron content down to an acceptable level.

The customary procedure applied to most massive deposits, such as alaskite, begins with drilling, blasting, and drop-ball breaking at the quarry, followed by primary and secondary crushing and fine grinding in jaw crushers, cone crushers, and rod mills, respectively. The sequence typically continues with acid-circuit flotation in three stages, each stage preceded by desliming and conditioning. The first flotation step typically depends on an amine collector to float off and remove mica, and the second uses sulfonated oils to separate iron-bearing minerals, most notably garnet. The third step, flotation with another amine collector, leaves behind a residue that consists chiefly of quartz. Sometimes the third step is bypassed, leaving a feldspar-silica mixture, which can be used in the manufacture of glass.

The flotation-cake feldspar or feldspar-silica mixture is dewatered in filters or drain bins and dried in rotary driers for use as glass-grade feldspar. Some material is further ground in pebble mills as pottery spar and for other uses.

Byproducts and Coproducts

Feldspar was obtained as a coproduct in 1991 from one company mining and processing lithium ore and one company treating weathered pegmatite ore containing mica and kaolin. Coproduct recovery of mica and silica sand was reported by some feldspar processors.

Economic Factors

Feldspar is largely sold in bulk and moved by rail hopper cars. Transportation can comprise 50% or more of the total delivered cost. Some

shipments are by truck. Most feldspar products are shipped no more than several hundred kilometers. An exception is premium-grade high-potash feldspar.

ANNUAL REVIEW

Feldspar

Legislation and Government Programs.—According to provisions of the Tax Reform Act of 1969, which continued in force throughout 1991, the depletion rate allowed on domestic and foreign feldspar production was 14%.

Production.—Feldspar or feldspar-silica sand was mined in seven States, led by North Carolina and followed, in descending order, by Oklahoma, Connecticut, California, Georgia, Idaho, and South Dakota. North Carolina accounted for 69% of the total. Nine U.S. companies operating 12 beneficiating plants and 1 grinding plant produced feldspar or feldspar-silica mixtures for shipment to more than 30 States and foreign countries, including Canada and Mexico. Of the nine companies, three produced potash feldspar, and the remainder produced soda or mixed (soda-potash) feldspar or feldspathic sand mixtures. North Carolina had five plants, California had two, and Connecticut, Georgia, Idaho, Oklahoma, and South Dakota each had one. The grinding plant was in South Carolina.

The U.S. Bureau of Mines uses a criterion of 8% minimum K_2O content in collecting data for potash feldspar.

In mid-1991, U.S. Silica Co. ceased operation at its Oceanside, CA, facility, which had been producing feldspar-silica sand. At yearend 1991, The Feldspar Corp. closed its Middletown, CT, plant. (See tables 1, 2, and 3.)

Consumption and Uses.—Fifty-five percent of feldspar sold or used in the United States went into glass, including glass containers and glass fiber. Feldspar going into pottery and other uses was

45% of the output. Lower feldspar consumption compared with that of 1990 followed the trend of the sluggish economy. Feldspar use in glass containers was also affected by competition from imported nepheline syenite. Reduced housing construction activity resulted in less feldspar demand in whiteware such as plumbing fixtures and tile.

In the rigid container market in 1990, market shares were metal cans, 62%; glass, 20%; and plastic, 18%.³ (See tables 4, 5, 6, 7, and 8.)

World Review.—Capacity.—The data in table 9 are rated capacity for mines and refineries as of December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. Because actual capacity data were not available, recent peak production during the past 5 years for the United States and foreign countries was considered to be equal to rated capacity. (See table 9.)

Costa Rica.—The most promising potential sources of feldspar appeared to be the feldspar quartz-phyric tuffs derived from volcanoes forming the Cordillera de Guanacaste. The tuffs were said to contain 30% to 40% feldspar. The relatively soft material would require only slight crushing and then froth flotation. Recovered quartz might be used for glassmaking. In Mexico, similar tuffs were being processed for glass-grade feldspar.⁴

Finland.—The two feldspar operations of Lohja Corp. Oy Ab were at Kimito (Kemio) in the extreme southwest of the country and at Alavus in western Finland.

Several pegmatites occurred within 4 to 5 kilometers of the Kimito plant and contained approximately 65% feldspar, 30% quartz, and 5% mica. About 100,000 tons per year of material was being mined, yielding about 40,000 tons per year of potash feldspar and 17,000 tons per year of quartz. Reserves were in excess of 20 years.

Both wet and dry processing was being employed, with the former including grinding, hydroclassification, magnetic separation, and flotation. The dry processing part of the plant included feed drying, screening, and magnetic separation. Additional high-intensity magnetic separators were installed in both wet and dry circuits. Two stages of hydroclassifiers were also incorporated. The new modifications were expected to be in operation by mid-1991 and were aimed at reducing impurity levels still further and ensuring product consistency. The glass and ceramic feldspar and quartz products were being exported to the Federal Republic of Germany, the Netherlands, Poland, and the United Kingdom.

At Alavus, the company's second feldspar operation, approximately 10,000 tons per year of pegmatite ore was being mined and subjected to dry magnetic separation. The potash feldspar product, with a low Fe_2O_3 content of 0.06%, was mostly being consumed in domestic glass and ceramics industries, especially sanitaryware.⁵

India.—Occurrences of feldspar have been reported in many parts of the country. Rajasthan has been the largest producing State with 61% of India's output in 1988. Total production has been in the range of 50,000 tons to 58,000 tons per year in recent years. In 1987, exports were approximately 13,900 tons of lump ore and 6,100 tons of powder. Exported material has gone to Bangladesh, China, Sri Lanka, Japan, Malaysia, the Philippines, Singapore, and Thailand. In India, major end uses of feldspar have been glass, ceramics, electrical porcelain, and vitreous enamels. In mid-1991, feldspar for export was \$32

to \$34 per ton, lump, f.o.b. Madras, and \$70 per ton, powdered, f.o.b. Madras.⁶

Spain.—The major feldspar producer, Industrias del Cuarzo SA, was mining a feldspathic deposit at Carrascal del Rio in Segovia. The company had proven reserves of 40 million tons and large probable reserves. The company's modern plant facilities included classification and washing, scrubbing and flotation, feldspar and sand separation, drying, grinding, micronizing, and iron removal. Capacities were 80,000 tons per year of potash feldspar, 140,000 tons per year of dry sand, and 60,000 tons per year of glass sand. About 54,000 tons per year of feldspar was being exported to France, Italy, Morocco, Portugal, and the United Kingdom.

Potash feldspar with 11.1% K₂O and 0.11% Fe₂O₃ was being sold for use in ceramics, frits, enamels, porcelain, china, sanitaryware, etc. Dry silica sand was sold for foundries, paint, fiber cement, reinforced concrete, mortars, etc.

A major expansion was planned for the next 5 years, which would raise feldspar production to 160,000 tons per year. Much of the increased output would be aimed at United Kingdom markets.

Llansa SA was obtaining mainly soda feldspar from massive pegmatites of granitic origin from quarries near Llanca in Gerona. Reserves were at least 5 million tons. Ore was crushed, washed to remove clays, hand sorted, secondary crushed, milled, and then passed through magnetic separation and air classification.

In 1990, Llansa produced 45,000 tons of soda-potash feldspar with 4.8% Na₂O and 4.3% K₂O, and 15,000 tons of soda feldspar with 6.8% Na₂O and 2% K₂O. End uses included sanitaryware, tableware, frits, enamels, pottery, electrical porcelain, glass, fillers, etc. Markets were mainly domestic.

Cia. Minera de Rio Piron SA emerged as a potash feldspar producer in 1989. The company operated a feldspathic sand deposit at Navas de Oro in Segovia. After flotation, drying, and magnetic separation, glass and ceramic grades of feldspar were produced. Ceramic grades were obtained by dry grinding to 150

mesh for enamels, 200 mesh for pottery, and 325 mesh for decorative and electrical porcelain. The company was selling about 30,000 tons per year to domestic markets, roughly equally divided between glass bottle and ceramics markets.

The fourth Spanish feldspar producer was Basazuri SL with a pegmatite deposit at Barreiros in Lugo. Output in 1988 was 79,000 tons of soda and potash feldspar. A fifth producer, Explotaciones Ceramicas Espanoles SA (Ecesa), may emerge at the end of 1992 with a low iron, potash feldspar deposit in Avila.

Imports of feldspar to Spain were approximately 42,800 tons in 1988, mainly from France. Exports were 4,000 tons in the same year, primarily to France and Morocco.⁷ (See table 10.)

Nepheline Syenite

Nepheline syenite was produced by Unimin Canada Ltd. from two operations at Blue Mountain and Nephon, Ontario, Canada. Shipments in 1989, the latest year for which information was available, were about 556,000 tons. A large portion was exported to the United States, with smaller quantities going to Europe and elsewhere. End uses included glass, whiteware, and as a filler and extender in paint, plastic, adhesives, and rubber.

In the latter part of 1991, preliminary reviews were made by the U.S. International Trade Commission (ITC) and the International Trade Administration to determine whether imported nepheline syenite from Canada was being sold at less-than-fair value. A final public hearing was to be held by the ITC in March 1992.

In Norway, nepheline syenite was produced at the Elkem Nefelin A/S, underground mining operation on the arctic island of Stjernøy. Output was 287,000 tons in 1988, the latest year for which data were available. Sales were largely to markets in Western Europe.

Prices for Canadian nepheline syenite listed in Industrial Minerals (London), December 1991, converted from Canadian dollars per short ton to U.S. dollars per ton, were approximately \$25

to \$32 per ton for glass grade, 30 mesh, bulk, carlots-trucklots, depending on iron content; \$75 per ton for ceramic grade, 200 mesh, bagged, 1-ton lots; and \$89 to \$102 per ton for filler-extender grade, bagged. (See table 11.)

Aplite

Aplite is a feldspar mineral that has more than one geological definition. However, apelite from the one active U.S. operation contains lime-soda feldspar. Aplite, usually unsuitable for use in ceramics, has been used in the manufacture of glass when it is sufficiently low in iron.

Aplite of glassmaking quality was produced in the United States by The Feldspar Corp. near Montpelier, Hanover County, VA. Domestic output decreased from that of 1990. The data are company proprietary and cannot be released for publication. Aplite traditionally has a somewhat lower price than feldspar. Industrial Minerals (London), December 1991, gave a value of about \$26 per ton for glass grade, bulk, 100% plus 200 mesh, f.o.b. Montpelier, VA.

With an annual production of 500,000 tons to 560,000 tons in recent years, Japan has been the world's largest producer of apelite. Italy is the world's largest producer of feldspathic materials, including feldspar and apelite; published figures did not give the relative breakdown of the two minerals products.

OUTLOOK

The glass container market, the largest outlet for feldspar, should remain stable in the near future. Competition will come especially from aluminum cans. To improve its standing, the glass container industry will want to work for improvements in the manufacturing process, lightweighting, strengthening the glass container, and labor productivity.⁸

Housing construction should improve at least modestly in 1992 after reaching a several-year low point of 1 million starts in 1991. Feldspar demand in plumbing fixtures and tile should likewise have at least a modest rebound.

¹Rogers, C. P., Jr., and J. P. Neal. Feldspars. Ch. in *Industrial Minerals and Rocks*, rev. by K. H. Teague. AIME, New York, 5th ed., 1983, p. 711.

²Ceramic Industry. *Materials Handbook*. V. 136, No. 1, Jan. 1991, p. 51.

³Glass Industry. Glass Has 20% Share of Rigid Market. V. 72, No. 1, Jan. 1991, p. 10.

⁴Berrange, J. P. *Industrial Minerals of Costa Rica*. Ind. Miner. (London), No. 288, Sept. 1991, p. 91.

⁵Benbow, J. Finland's Mineral Industry—Turning to Stone. Ind. Miner. (London), No. 283, Apr. 1991, pp. 25-26.

⁶Russell, A. India—A Treasure Trove of Minerals. Ind. Miner. (London), No. 287, Aug. 1991, p. 29.

⁷Griffiths, J. Spain's Minerals—Mixed Fortunes. Ind. Miner. (London), No. 285, June 1991, pp. 40-42.

⁸Perrine, L. E. Glass Problems Conference Features an Industry Status Report. *Glass Industry*, v. 72, No. 1, pp. 19.

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Lesure, F. G. Feldspar. Ch. in *United States Mineral Resources*. U.S. Geol. Surv. Prof. Paper 820, 1973, pp. 217-222.

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Roskill Information Services Ltd. (London). *The Economics of Feldspar 1990*, 6th ed., 190 pp.

**TABLE 1
SALIENT FELDSPAR AND NEPHELINE SYENITE STATISTICS**

		1987	1988	1989	1990	1991
United States:						
Feldspar:						
Produced ¹	metric tons	655,000	650,000	655,000	630,000	580,000
Value	thousands	\$26,100	\$26,400	\$28,000	\$27,400	\$26,000
Exports	metric tons	8,740	12,439	9,329	24,795	8,425
Value	thousands	\$691	\$769	\$829	\$2,167	\$1,334
Imports for consumption	metric tons	4,384	6,193	12,003	11,318	17,876
Value	thousands	\$477	\$659	\$873	\$723	\$1,124
Nepheline syenite:						
Imports for consumption	metric tons	280,034	281,086	303,000	276,000	289,000
Value	thousands	\$11,401	\$11,233	\$12,273	\$12,200	\$13,069
Consumption, apparent² (feldspar plus nepheline syenite)						
	thousand metric tons	931	925	961	893	878
World: Production (feldspar)	do.	¹ 4,383	¹ 4,843	¹ 5,181	¹ 5,269	¹ 5,167

¹Estimated. ²Revised.

¹Includes hand-cobbed feldspar, flotation-concentrate feldspar, and feldspar in feldspar-silica mixtures; includes potash feldspar (8% K₂O or higher).

²Production plus imports minus exports.

**TABLE 2
FELDSPAR¹ PRODUCED IN THE UNITED STATES**

Year	Hand-cobbed		Flotation concentrate		Feldspar-silica mixtures ²		Total ³	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1987	10	W	446	\$17,800	199	W	655	\$26,100
1988	13	W	452	18,657	185	W	650	26,400
1989	11	W	425	16,915	219	W	655	28,000
1990	W	W	437	15,815	W	W	630	27,400
1991	W	W	362	14,266	W	W	580	26,000

W Withheld to avoid disclosing company proprietary data; included in "Total."

¹Includes potash feldspar (8% K₂O or higher).

²Feldspar content.

³Data may not add to totals shown because of independent rounding.

**TABLE 3
PRODUCERS OF FELDSPAR AND FELDSPATHIC MATERIALS IN 1991**

Company	Plant location	Product
APAC Arkansas Inc.	Muskogee, OK	Feldspar-silica mixture.
Corona Industrial Sand Co.	Corona, CA	Do.
The Feldspar Corp.	Middletown, CT	Soda-potash feldspar.
Do.	Monticello, GA	Potash feldspar.
Do.	Spruce Pine, NC	Soda-potash feldspar.
Do.	Montpelier, VA	Aplite.
KMG Minerals, Inc.	Kings Mountain, NC	Potash feldspar.
KT Feldspar Corp.	Spruce Pine, NC	Soda-potash feldspar.
Lithium Corp. of America	Bessemer City, NC	Feldspar-silica mixture.
Pacer Corp.	Custer, SD	Potash feldspar.
Spartan Minerals Corp.	Pacolet, SC	Feldspar-silica mixture.
Unimin Corp.	Emmett, ID	Do.
Do.	Spruce Pine, NC	Soda-potash feldspar.
U.S. Silica Co.	Oceanside, CA	Feldspar-silica mixture.

**TABLE 4
FELDSPAR¹ SOLD OR USED BY PRODUCERS IN THE UNITED STATES,
BY USE**

(Thousand metric tons and thousand dollars)

Use	1990		1991	
	Quantity	Value	Quantity	Value
Hand-cobbed:				
Pottery	W	W	W	W
Other	W	W	W	W
Total ²	W	W	W	W
Flotation concentrate:				
Glass	162	7,270	144	6,330
Pottery	234	14,178	222	13,564
Total ²	395	21,448	366	19,894
Feldspar-silica mixtures:³				
Glass	175	10,617	161	10,573
Pottery	W	W	W	W
Total ²	W	W	W	W
Total:²				
Glass ⁴	337	17,887	305	16,903
Pottery	W	W	W	W
Other ⁵	W	W	W	W
Total	600	34,100	550	32,400

W Withheld to avoid disclosing company proprietary data; included in "Total."

¹Includes potash feldspar (8% K₂O or higher).

²Data may not add to totals shown because of independent rounding.

³Feldspar content.

⁴Includes container glass and glass fiber.

⁵Includes enamel, filler, etc., and unknown.

TABLE 5
POTASH FELDSPAR¹ SOLD OR
USED BY PRODUCERS IN THE
UNITED STATES

(Thousand metric tons and thousand dollars)

Year	Quantity	Value
1990	61	5,765
1991	52	5,135

¹K₂O content of 8% or higher.

TABLE 6
PRICES FOR FELDSPAR

(Dollars per metric ton, f.o.b. plant, bulk)

Producing States	1990	1991
Ceramic grade:		
Middleton, CT, minus 200 mesh	74.41	74.41
Monticello, GA, 200 mesh, high potash	90.94	90.94
Spruce Pine, NC, 170 to 250 mesh	55.12	55.12
Glass grade:		
Middleton, CT, 96% plus 200 mesh	50.16	50.16
Monticello, GA, 92% plus 200 mesh, high potash	71.38	71.38
Spruce Pine, NC, 97.8% plus 200 mesh	36.93	36.93

Source: Industrial Minerals (London), No. 279, Dec. 1990, p.78, and No. 291, Dec. 1991, p. 62.

TABLE 7
U.S. EXPORTS OF FELDSPAR, BY COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Canada	2,555	\$273,133	2,141	\$222,600
Dominican Republic	326	71,869	215	40,705
Germany, Federal Republic of	1,878	142,491	—	—
Italy	1,796	242,398	2,334	436,856
Mexico	1,536	236,668	648	102,226
Netherlands	14,075	829,743	1,197	126,896
Taiwan	238	72,316	395	123,698
United Kingdom	710	75,255	39	4,114
Venezuela	238	9,262	774	113,999
Other	769	213,647	682	162,683
Total	24,795	2,166,782	8,425	1,333,777

Source: Bureau of the Census.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF FELDSPAR, BY COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value ¹	Quantity (metric tons)	Value ¹
Canada	—	—	19	\$10,640
Germany, Federal Republic of	69	\$22,142	52	20,240
Mexico	11,249	700,638	17,805	1,093,208
Total	11,318	722,780	17,876	1,124,088

¹Customs value.

Source: Bureau of the Census.

TABLE 9
WORLD FELDSPAR ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1991

(Thousand metric tons)

	Rated capacity ¹
North America:	
Mexico	195
United States	665
Total	860
South America:	
Brazil	121
Venezuela	100
Other	190
Total	411
Europe:	
Finland	56
France	420
Germany	338
Italy	1,590
Norway	90
Poland	57
Portugal	66
Romania*	86
Spain	196
Sweden	40
U.S.S.R.*	330
Yugoslavia	50
Other	16
Total	3,335
Africa:	
South Africa, Republic of	82
Other	65
Total	147
Asia and Oceania:	
India	58
Japan	92
Korea, Republic of	242
Thailand	520
Turkey	175
Other	139
Total	1,226
World total²	5,980

*Estimated.

¹Includes capacities of operating plants as well as plants on standby basis.

²Data do not add to total shown because of independent rounding.

TABLE 10
FELDSPAR: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991 ^a
Argentina	29,282	39,469	23,688	*24,000	23,000
Australia	11,499	15,877	*15,000	*16,000	16,000
Austria	4,692	8,222	7,251	*8,788	8,500
Brazil ³	118,608	109,534	*120,000	*95,000	95,000
Burma ⁴	*5,619	*4,938	*1,812	*2,476	2,500
Chile	705	4,569	*8,081	*2,980	3,000
Colombia	33,760	37,136	40,850	*34,800	35,000
Ecuador	1,558	5,000	*21,814	*8,000	9,000
Egypt	15,963	6,131	27,731	*9,894	27,000
Finland	51,632	56,200	54,581	*52,630	52,000
France	274,000	322,000	360,000	*420,000	400,000
Germany, Federal Republic of,					
Western states	310,447	308,776	*332,600	*337,600	325,000
Guatemala	7,669	*8,959	*7,000	*11,895	12,000
Hong Kong	22,853	11,050	5,152	*3,820	3,500
India	49,663	57,656	56,690	*54,000	55,000
Iran	*16,226	*14,781	*20,458	*30,000	30,000
Italy	1,188,700	1,367,776	1,350,733	*1,590,339	1,500,000
Japan ⁵	33,754	29,465	43,137	*57,877	92,201
Kenya	—	—	1,112	*1,290	1,300
Korea, Republic of	180,269	241,511	232,607	*237,447	235,000
Mexico	106,490	83,170	*121,978	*163,011	*194,506
Morocco ⁶	1,000	1,000	1,000	1,000	1,000
Nigeria	485	190	945	*714	700
Norway ⁷	90,000	90,000	90,000	90,000	90,000
Pakistan	6,675	9,026	7,703	*10,249	10,000
Peru	64,749	*2,378	*10,000	*10,000	10,000
Philippines	11,996	9,199	*36,803	*46,102	45,000
Poland ⁸	*55,000	50,000	50,000	*45,000	45,000
Portugal	40,729	51,903	65,854	*43,954	45,000
Romania ⁹	82,000	*75,000	*59,960	*55,000	53,000
South Africa, Republic of	*50,930	*61,440	*52,964	56,124	*70,308
Spain ⁸	161,631	195,668	*155,000	*150,000	150,000
Sri Lanka	7,442	6,345	6,656	*9,698	9,500
Sweden	34,226	*38,180	*38,437	*40,000	40,000
Taiwan	28,116	19,101	9,806	*7,321	7,000
Thailand	168,881	293,678	515,206	*311,249	320,000
Turkey	30,336	82,225	90,751	*155,000	175,000
U.S.S.R. ⁹	330,000	330,000	330,000	300,000	250,000
United Kingdom (china stone)	5,692	*6,422	6,470	*6,257	6,000
United States	655,000	650,000	655,000	630,000	*580,000
Uruguay	3,016	2,787	2,680	*3,000	3,000
Venezuela	43,546	96,500	97,000	*91,000	95,000
Yugoslavia	44,912	35,615	*44,246	*43,490	40,000
Zambia	45	120	20	*60	80

See footnotes at end of table.

TABLE 10—Continued
FELDSPAR: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991 ³
Zimbabwe	2,962	3,730	2,697	2,197	2,200
Total	4,382,758	4,842,727	5,181,473	5,269,262	5,167,295

¹Estimated. ²Revised.

³Table includes data available through Apr. 20, 1992.

⁴In addition to the countries listed, Czechoslovakia, Madagascar, and Namibia produce feldspar, but output is not officially reported, and available general information is inadequate for the formulation of reliable estimates of output levels.

⁵Series excludes production of leucite and sodalite; data consist only of that material reported by Brazil under the heading of "Feldspar." Data represent the sum of (1) run-of-mine production for direct sale and (2) salable beneficiated product; total run-of-mine feldspar production was as follows, in metric tons: 1987-98,828; 1988-140,041; 1989-140,651 (revised); 1990-104,000 (revised estimated); and 1991-100,000 (estimated).

⁶Data are for fiscal years beginning Apr. 1 of that stated.

⁷In addition, the following quantities of aplite ore were produced in metric tons: 1987-466,429; 1988-526,285; 1989-562,823; 1990-522,744 (revised); and 1991-500,327.

⁸Reported figure.

⁹Excludes nepheline syenite.

¹⁰Includes pegmatite.

TABLE 11
**U.S. IMPORTS¹ FOR
 CONSUMPTION OF NEPHELINE
 SYENITE**

Year	Quantity (metric tons)	Value ² (thousands)
1989	303,000	\$12,273
1990	276,000	12,200
1991	289,000	13,069

¹Crude and ground combined since 1989.

²Customs value.

Source: Bureau of the Census.

FLUORSPAR

By M. Michael Miller

Mr. Miller, a physical scientist with 14 years of mineral experience with the Department of the Interior, has been the commodity specialist for fluorspar since 1989. Domestic survey data were prepared by Tonya Hardin, statistical assistant; and international data tables were prepared by Harold Willis, international data assistant. All units are in metric tons, unless otherwise noted.

In the United States, one major producer supplied about 12% of the Nation's fluorspar requirements, shipping primarily to the producer's parent chemical company. Supplementing fluorspar as a domestic source of fluorine was byproduct fluosilicic acid production from some phosphoric acid producers. According to the Bureau of the Census, imports of fluorspar decreased by about 27% compared with those of 1990. Hydrofluoric acid (HF) imports were about 19% lower than those reported in the previous year.

DOMESTIC DATA COVERAGE

Domestic production and consumption data for fluorspar were developed by the U.S. Bureau of Mines from voluntary surveys of U.S. operations. Surveys were conducted to obtain fluorspar mine production and shipments and fluosilicic acid production. Of the five fluorspar mining operations to which a survey request was sent, four responded, representing 100% of known domestic shipments. Production statistics in table 1 are withheld to protect company proprietary data. Of the 10 fluosilicic acid producers surveyed, 8 of 10 respondents reported production, representing 100% of the quantity reported. The consumption survey was sent to 91 operations quarterly and to 40 additional operations annually. Of the operations surveyed quarterly, 68% responded. Of the operations surveyed on an annual basis, 70% responded. Together, quarterly and annual responses

exceeded the apparent consumption data shown in table 1. This discrepancy between the reported and apparent consumption was caused by missing import data and a large quantity of reexports. These two factors made the apparent consumption lower than the reported consumption. (See table 1.)

BACKGROUND

Definitions, Grades, and Specifications

Technically, pure fluorspar, or the mineral fluorite, contains 51.1% calcium and 48.9% fluorine. Natural fluorite is commonly associated with other minerals such as quartz, barite, calcite, galena, siderite, celestite, sphalerite, chalcopyrite, other sulfides, and phosphates. It occurs in well-formed isometric crystals, in massive and earthy forms, and as crusts or globular aggregates with radial fibrous texture. In crystalline form, it can be colorless or may exhibit a wide range of colors, including yellow, blue, purple, green, rose, red, bluish and purplish black, and brown. It has a hardness of 4 on the Mohs' scale, a specific gravity ranging from 3.01 to 3.60, and a melting point of 1,378° C.

Three principal grades of fluorspar are available commercially: acid, ceramic, and metallurgical. Although the specifications for individual grades are generally well defined, some variation is permitted to satisfy the requirements of individual consumers.

In the United States, acid-grade fluorspar (acidspar) contains at least 97% CaF_2 . Some manufacturers of hydrofluoric acid in the United States and Europe can use 96% CaF_2 or slightly lower if the remaining impurities are acceptable. User specifications may impose limits on silica, calcium carbonate, sulfide or free sulfur, calcite, beryllium, arsenic, lead, phosphates, and other constituents. Moisture content of the dried material is preferably 0.1% or less. Particle size and distribution are sometimes specified for proper control of the rate of chemical reaction and stack losses. Very few reserves in the world can be used to produce acid-grade fluorspar without flotation processing.

Ceramic-grade fluorspar is generally marketed as No. 1 ceramic, containing 95% to 96% CaF_2 , and No. 2 ceramic, containing 85% to 90% CaF_2 . An intermediate grade of about 93% to 94% CaF_2 is also available. Specifications on impurities vary, but may allow a maximum of 2.5% to 3.0% silica, 1.0% to 1.5% calcite, 0.12% ferric oxide, and trace quantities of lead and zinc. Shipments of ceramic-spar are usually tailored to the specific need of individual consumers.

Metallurgical-grade fluorspar (metspar) contains a minimum of 60% effective CaF_2 . In the United States, metspar is usually quoted in terms of effective CaF_2 units, obtained by subtracting 2.5 times the silica content of the ore from its total CaF_2 content. The term "metspar" is usually used to refer to material with a maximum CaF_2 content of 85%, but

sometimes is used for material as high as 96%, which includes what is technically ceramic grade. Other countries may require a minimum of 80% CaF₂, which allows larger quantities of silica, usually a maximum of 15%, and other contaminants. Metspar is often traded as a lump or gravel that must pass a 25- to 37.5-millimeter screen (1 to 1 1/2 inch) and contain less than 15% of material passing a 1.6-millimeter screen (1/16 inch).

In the domestic steel industry, various shapes and sizes of briquets or pellets are being used. Generally made to consumer specifications, briquets contain varying quantities of fluorspar mixed with binders, fillers, and fluxing agents. Typically made on roll presses and ranging in size from that of a peach seed to a 5-centimeter square, briquets contain 25% to 90% CaF₂ and steel mill waste ingredients, such as mill scale, flue dust, shredded scrap, iron ore fines, and manganese ore fines. The most popular binders are molasses and lime, which do not require baking ovens. Imported briquets are often made from fines accumulated during metspar preparation and from flotation concentrates. Pellets have been made on balling machines using sodium silicate binder.

Geology-Resources¹

Fluorspar occurs in a wide variety of geological environments, which indicates that deposition takes place in a number of different ways. From an economic standpoint, seven of the most important modes of occurrence are as follows:

1. Fissure vein deposits commonly occur along faults or shear zones and are the most readily recognized form of fluorspar occurrence in the world. Although the vein structure may be persistent, the fluorspar mineralization commonly occurs as lenses or ore shoots separated by barren zones. Fissure veins occur in igneous, metamorphic, and sedimentary rocks.

2. Stratiform, manto, or bedded deposits occur as replacements in carbonate rocks. Some beds are replaced adjacent to structural features such as

joints and faults. Frequently, there is a capping of sandstone, shale, or clay.

3. Replacement deposits in carbonate rocks along the contact with acidic igneous intrusives are another common type of deposit. Deposits do not have to be the result of contact metamorphism, but may be introduced later, following the contact zone as a conduit and replacing the limestone.

4. Stockworks and fillings in shear and breccia zones are another form in which fluorspar occurs. The Buffalo deposit in the Transvaal consists of a network of fluorspar veinlets in sill-like bodies that are inclusions in the granite of the Bushveld complex.

5. Carbonatite and alkalic rock complexes may have fluorspar at their margins. Fluorspar grades are not usually sufficient to be economic, but the Okorusu deposit in Namibia is made up of a number of bodies of fluorspar in limestones, quartzites, and related rocks that have been intruded and metamorphosed by an alkaline igneous rock complex.

6. Residual deposits of fluorspar are formed in clayey and sandy residuum that results from surficial weathering of fluorspar veins and replacement deposits. These deposits may be the sources of metallurgical-grade fluorspar. They include detrital deposits blanketing the apex of veins and the upper portions of the veins themselves that have been weathered to depths of 30 meters or more.

7. Fluorspar may also occur as a major gangue mineral in lead and zinc vein deposits. Two operations in the Parral area of Mexico have treated the tailings of lead-zinc mines to recover fluorspar from previously discarded gangue minerals.

Identified world fluorspar resources are approximately 365 million tons of contained fluorspar. As might be expected, the countries with the highest production have the largest fluorspar reserves, although their production ranking does not necessarily mirror their reserve ranking. World resources of equivalent fluorspar from phosphate rock are approximately 325 million tons,

which includes about 32 million tons from domestic phosphate rock. (See table 2.)

Technology

Mining.²—Mining methods vary according to geologic conditions at individual deposits around the world. Deep deposits usually require underground techniques, while wide, shallow deposits employ open pit methods. If the ground is unable to support underground mining, open pit methods may be used even though overburden removal might be substantial. In some cases, open pit methods are used until the mining reaches a practical production limit because of excessive waste removal. Mining operations then move underground.

Narrow vein mining is often done by shrinkage stoping and open stoping where strong walls occur, while stratiform or bedded deposits use room-and-pillar patterns. Replacement and fissure vein deposits are mined with shrinkage stoping or cut-and-fill methods if they are deep, narrow occurrences. They may also be mined by open pit or strip-mining techniques when they occur near the surface and have competent sidewalls. The replacement and stockwork deposits in the Republic of South Africa, the carbonatite deposit in Namibia, and most of the fissure veins in Thailand are mined with open pit methods. However, replacement deposits in Mexico are extracted by stoping or cut-and-fill methods.

Beneficiation.—Most fluorspar must be upgraded for marketing. Metspar is often produced by hand sorting of high-grade lump crude ore, followed by crushing and screening to remove most of the fines. In the case of fluorspar ores of lower grade and/or ores with relatively coarse interlocking of minerals, gravity concentration processes are used based on the specific gravity above 3.0 for spar and below 2.8 for most gangue minerals.

Heavy-media cone and drum separators are particularly effective in the 37.5- by

4.75-millimeter (1 1/2- by 3/16-inch) size range, either for producing metallurgical gravel or for preconcentrating crude ore for flotation feed. For the finer sizes, the heavy-media cyclone process is frequently used. The high capacity and low operating cost of heavy-media methods give very satisfactory results. Ores as low as 14% CaF₂ can be preconcentrated to yield a flotation feed of 40% CaF₂ or more. In the process, lead and zinc sulfides and barite concentrate with the fluorspar, which enriches the flotation feed with these valuable minerals. In some cases, washing plants are also used prior to flotation to remove clay or manganese oxides (wad).

Ceramic and acid grades of fluorspar are produced by multistage froth flotation. Ore from the mine is crushed and ground to proper size; care is taken not to overgrind and cause fluorspar to be lost in the slimes. If lead and zinc sulfides are present, they are preferentially floated off with xanthate collector. After this process is completed, all the easy floating fluorspar is removed in a quick pass through a flotation circuit and sent on to the cleaner circuit. The tailings are discarded. The middling product is reground to separate the more finely interlocked grains of fluorspar and gangue and passed through one or more cleaner circuits. The final products generally comprise an acid-grade concentrate and, in some cases, one or more concentrates of lower grade, which are sold as ceramic grade, or pelletized and sold as metallurgical grade. Fatty acids are used as collectors for the fluorspar. Quebracho or tannin is used to depress calcite and dolomite; sodium silicate is used to depress iron oxides and silica; and chromates, starch, and dextrin are used to depress barite. Cyanide is used to depress any remaining sulfides. Lime, caustic, or soda ash can be used for acidity control. Flotation temperatures range from ambient to 80° C.

ANNUAL REVIEW

Legislation and Government Programs

The Defense Logistics Agency, Defense National Stockpile Center (DLA-DNSC), measures the fluorspar stockpile in standard dry tons (sdt). In 1991, it was authorized to sell 10,000 sdt (9,072 metric tons) of metallurgical-grade fluorspar during fiscal year 1991. The material offered is stockpiled near Gallup, NM. It is of nonstockpile grade and has an effective calcium fluoride content of 59%. There were no fluorspar stockpile sales during 1991. According to the revised fiscal year 1992 annual materials plan of DLA-DNSC, there is an existing authority for the disposal of 20,000 sdt (18,144 metric tons) of metallurgical-grade material.

Major changes in the fluorspar stockpile may occur. Based on revised national security needs required by new post-cold war planning assumptions, the Department of Defense has requested that Congress authorize disposal of significant portions of the National Defense Stockpile, including the entire fluorspar stockpile. The mechanism for this disposal would be the requested authorization for the Department of Defense to dispose of up to \$1 billion in excess stockpile inventories in any fiscal year.³

Depletion allowances against Federal taxes of 22% and 14%, respectively, remained in effect for domestic and foreign production by U.S. companies.

On November 15, 1990, the Clean Air Act Amendments of 1990 (CAAA) were enacted into law. Title VI covered stratospheric ozone protection and was directed primarily at chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) chemicals. Section 612 of title VI addressed a "Safe Alternatives Policy." Under this policy the U.S. Environmental Protection Agency (EPA) was required to promulgate, within 2 years of enactment of the CAAA, rules providing that it shall be unlawful to replace any class I (CFC's) or class II

(HCFC's) substance with any substitute substance that may present adverse effects to human health or the environment, where the EPA has identified an alternative to such replacement that reduces the overall risk to human health and the environment and is currently available. The EPA shall publish a list of the substitutes prohibited for specific uses and a list of the safe alternatives for specific uses.⁴

The risk assessment phase of this policy involves evaluation of ozone-depletion potential, global warming potential, toxicity, and flammability. This is followed by the risk management phase, where alternatives will be evaluated and compared by use.

Some CFC producers expressed opposition to this policy, because companies may be reluctant to invest in alternative chemicals that may have no value after the prohibition list is published.

Section 606 of title VI authorized the EPA to accelerate the phaseout schedules, if new scientific evidence warrants it, the availability of substitutes makes it practical, or the Montreal Protocol on Substances That Deplete the Ozone Layer is modified to include a phaseout schedule more accelerated than the one under this law. The latest scientific evidence, as reported by the National Aeronautics and Space Administration and the European Stratospheric Ozone Experiment, indicates a greater threat of ozone depletion than expected. In February 1992, the President announced that the United States would phaseout production of CFC's by the end of 1995, 4 years earlier than required by the Montreal Protocol. An accelerated international phaseout schedule will likely be adopted when signees of the Montreal Protocol meet in Copenhagen in November 1992.

Section 301(n)(6) of title III of the CAAA directed the EPA to complete a study of "the industrial and commercial applications of hydrofluoric acid in industrial and commercial applications to public health and the environment considering a range of events including worst-case accidental releases and shall make recommendations to the Congress

for the reduction of such hazards, if appropriate." During the course of the report preparation several questions were raised: (1) "Why should this study focus solely on hydrogen fluoride (HF) when it is only one of a number of toxic materials used industrially throughout the United States?" (2) "What is the difference between anhydrous HF and hydrofluoric acid, and do they pose the same hazards?" (3) "Is HF unique among hazardous chemicals in terms of its characteristics upon release or process safety management requirements?" (4) "There have been some serious incidents involving HF in the United States. What is the potential for a major disaster? What should be done to ensure that there is not a major disaster?" (5) Are the facilities handling HF aware of the potential hazards associated with a release of HF, and are they prepared to deal with a release?" (6) Is a community which has an HF facility located nearby aware of the hazards associated with a release of HF, and is the general public prepared to deal with a release?" (7) "Do other countries share our concerns, and if so, what is being done?" The EPA will attempt to address some of these questions while responding to the statutory requirements of the CAAA. A draft report was scheduled to be distributed for technical review in May 1992, while the final report was expected to be released in November 1992.⁵

Issues

As a result of the latest scientific evidence indicating that the rate of ozone depletion is greater than expected, there is pressure to speed up the phaseout of HCFC compounds and to move up the date for the outright ban to the year 2005 or earlier. This could have a pronounced effect on those consuming industries that are depending on HCFC's to replace CFC's. Commercial refrigeration and air conditioning systems depend on HCFC-22, while manufacturers of polystyrene, polyethylene, and polyurethane foams are expected to depend on blowing agents such as HCFC-142b, HCFC-141b, and HCFC-123.

Makers of refrigerators, air conditioners, and foam insulation oppose the accelerated phaseout of HCFC's. These industries have stated that they lack commercially viable alternatives necessary to eliminate the use of HCFC's. The air conditioning and refrigeration industry utilizes HCFC-22 in about 80% of its products, but no drop-in replacement will be available in the near future. These consuming industries argue that they need the HCFC's to bridge the gap between existing CFC-based technology and hydrofluorocarbon-based technologies. A major difficulty is that the consuming industries need to develop equipment design improvements to accommodate replacement compounds, while not knowing for sure which compounds will be available.

Production

Illinois was the only State reporting production in 1991 and accounted for 100% of all reported U.S. shipments. Data on shipments of fluorspar by State and grade are withheld to avoid disclosing company proprietary data.

Ozark-Mahoning Co., the Nation's largest fluorspar producer and a subsidiary of Elf Atochem North America Inc., operated three mines and a flotation plant in Pope and Hardin Counties, IL. Ozark-Mahoning also dried imported fluorspar to supplement its production. Seaforth Mineral & Ore Co. Inc. dried imported fluorspar at its facilities at Cave-In-Rock, IL, and East Liverpool, OH, for sale primarily to consumers in the ceramic industry. J. Irving Crowell, Jr., & Son shut down its Crowell-Daisy Mine in Nye County, NV. The Reynolds Mining Corp. mill in Eagle Pass, TX, was shut down in July of 1990 and was subsequently sold to Mexico's Sesa Fluorspar, Inc. The plant was dismantled and shipped to Mexico.

Ozark-Mahoning's Exploration Department operated five drills during 1991 and experienced a reasonable amount of success. At its Minerva No. 1 Mine, the company continued to mine on the new Cross Cut ore body. This trend is contrary to the normal trend direction

and was overlooked by the former mine owner Inverness Mining. To date, Ozark-Mahoning has mined more than 460 meters along the trend. It has completed test work on the column flotation of zinc ores and has purchased flotation columns for delivery in May 1992.

Eight plants processing phosphate rock for the production of phosphoric acid sold a reported 62,331 tons of byproduct fluosilicic acid at a value of about \$8.7 million. This was equal to 109,703 tons of 92% fluorspar equivalent.

Consumption and Uses

Acid-grade fluorspar, containing greater than 97% calcium fluoride (CaF_2), was used primarily as a feedstock in the manufacture of HF. Ceramic-grade fluorspar, containing 85% to 95% CaF_2 , was used for the production of glass and enamel, to make welding rod coatings, and as a flux in the steel industry. Metallurgical-grade fluorspar, containing 60% to 85% or more CaF_2 , was used primarily as a fluxing agent by the steel industry. Fluorspar is added to the slag to make it more reactive. It increases the fluidity of the slag (by reducing its melting point) and thus increases the chemical reactivity of the slag. Reducing the melting point of the slag brings lime and other fluxes into solution to allow the absorption of impurities.

Reported domestic consumption by the HF industry in 1991 remained essentially unchanged. Reported consumption by the steel industry decreased by about 52%, part of which was accounted for by a decrease in U.S. raw steel production of 13%.

In the ceramic industry, fluorspar was used as a flux and as an opacifier in the production of flint glass, white or opal glass, and enamels. Fluorspar was used in the manufacture of aluminum, brick, cement, and glass fibers, and was also used in the melt shop by the foundry industry.

Three companies reported fluorspar consumption for the production of HF. The U.S. Department of Commerce,

Bureau of the Census, reported that, based on its monthly survey, anhydrous, technical, and aqueous HF, 100% basis, "produced and withdrawn from the system," was 143,658 tons for 1991 compared with the 1990 quantity of 140,295 tons.

The largest use of HF was for the production of a wide range of fluorocarbon chemicals, including fluoropolymers and CFC's. CFC's were produced by five companies: Allied-Signal Corp., Ausimont USA Inc., E. I. du Pont de Nemours & Company Inc., Elf Atochem North America Inc., and La Roche Chemicals Inc. According to preliminary data from the U.S. International Trade Commission, production of trichlorofluoromethane (CFC-11) decreased by 27% to 44,815 tons and dichlorodifluoromethane (CFC-12) also decreased by 27% to 69,340 tons compared with 1990 figures. Data on production of chlorodifluoromethane (HCFC-22) were unavailable. No information is currently collected on production of the HCFC and HFC replacement compounds.

As a consequence of the announced accelerated schedule CFC-11 and CFC-12 production will be phased out by 1996. Because HCFC-22 is not a fully halogenated CFC and has a much lower ozone-depletion potential, it will be phased out at a later date, but earlier than had originally been proposed. The chemical industry continued to pursue research into replacement compounds for the CFC's and HCFC's that are to be phased out. Construction continued on commercial plants to manufacture some of the replacements. The CFC producers are developing HCFC substitutes that have ozone-depletion potentials of about 5% that of CFC-11, CFC-12, and CFC-113, which in total have accounted for more than 90% of CFC consumption. The most likely HCFC candidates to replace controlled CFC's are HCFC-22, for use in home air-conditioning (already in commercial use); HCFC-123, to replace CFC-11 as a blowing agent in polyurethane foams and refrigeration; HCFC-141b, to replace CFC-11 in blowing plastic foams; and HCFC-142b,

to replace CFC-11 as a blowing agent for polystyrene and polyethylene foams. Unfortunately, the viability of some of the HCFC compounds has been called into question owing to the likelihood that the phaseout schedule for HCFC's will be accelerated. In addition, HCFC-123 has run into toxicity and cost problems, and atmospheric measurements have indicated that the ozone depletion potential of HCFC-141b is much higher than originally calculated. The HFC substitutes have no ozone-depletion potential because they contain no chlorine atoms. The most promising HFC candidates are HFC-134a, to replace CFC-12 in refrigeration and auto air conditioners, and HFC's 32, 125, and 152. The latter three HFC's hold potential for use by themselves or as blends in mid- to low-temperature refrigeration and automobile air conditioners. In addition, some of the replacements may be mixtures of these compounds and HCFC's. Inhalation and toxicity tests continued on the various replacements.

The manufacture of synthetic cryolite and aluminum fluoride for use in aluminum reduction cells was a major use of HF. In the Hall-Héroult process, alumina is dissolved in a bath of molten cryolite, aluminum fluoride, and fluorspar to allow electrolytic recovery of aluminum. An estimated 20 to 30 kilograms of fluorine was consumed for each metric ton of aluminum produced. Aluminum fluoride was used by the ceramic industry for some body and glaze mixtures and in the production of specialty refractory products. It was used in the manufacture of aluminum silicates and in the glass industry as a filler.

HF was consumed in the manufacture of uranium tetrafluoride that was used in the process of concentrating uranium isotope 235 for use as nuclear fuel and in fission explosives. It was also used in stainless steel pickling, petroleum alkylation, glass etching, oil and gas well treatment, and as a cleaner and etcher in the electronics industry. It was used as the feedstock in the manufacture of a host of fluorine chemicals used in dielectrics, metallurgy, wood preservatives,

herbicides, mouthwashes, decay-preventing dentifrices, plastics, and water fluoridation.

Fluosilicic acid was used primarily to make aluminum fluoride for the aluminum industry and in water fluoridation, either directly or after processing to sodium silicofluoride. (See table 3.)

Stocks

Consumer stocks were 68,999 tons, a decrease of almost 8% from the level reported in 1990. At yearend, the National Defense Stockpile fluorspar inventory was unchanged from yearend 1990 and contained 892,000 sdt (809,000 metric tons) of acid-grade material, 310,000 sdt (281,000 metric tons) of metallurgical-grade material, 899 sdt (816 metric tons) of nonstockpile, acid-grade material, and 116,777 sdt (105,938 metric tons) of nonstockpile, metallurgical-grade material. The fluorspar stockpiles are at 22 sites across the country. The largest acid-grade stockpiles are in Wilmington, DE; Memphis, TN; and North Gate, CO. The largest metallurgical-grade stockpiles are in Marietta, PA; Large, PA; and Warren, OH.

Prices

According to prices published by Industrial Minerals (Metal Bulletin PLC), the price of domestic acid-grade fluorspar was unchanged compared with 1990 prices. Published yearend producer prices for Mexico and South Africa decreased compared with 1990 prices. Although not published in 1990, prices published in 1991 for Chinese fluorspar were significantly lower than those of other producers.

Yearend price quotations from the Chemical Marketing Reporter (CMR) were unchanged at \$0.6875 per pound for anhydrous HF and were unchanged at \$52.00 per 100 pounds for aqueous HF, 70%, in tanks. These quotations were equivalent to about \$1.52 per kilogram for anhydrous HF and \$114.64 per 100 kilograms for aqueous HF, 70%, in

tanks. The CMR yearend price quotation for fluosilicic acid, 100% basis, in tanks, was unchanged at \$340 per short ton (about \$375 per metric ton) and for synthetic cryolite ranged from \$510 to \$550 per short ton (about \$562 to \$606 per metric ton). (See table 4.)

Foreign Trade

According to the Bureau of the Census, U.S. exports of fluorspar increased by 395%. Almost 59,000 tons was exported to Mexico, which received 80% of U.S. fluorspar exports. The large export numbers reported by the Bureau of the Census reflect material classified as general imports, which is merchandise entered into customs bonded warehouses and U.S. foreign trade zones from foreign countries. This material, when transhipped to another country, appears in the trade statistics as U.S. exports. (See table 5.)

Imports for consumption of fluorspar decreased by about 27% compared with those of the previous year, according to Bureau of the Census data. However, based on reported consumption and domestic shipments, the decrease appeared to be about 18%. It is believed that there were some Chinese shipments unreported in the official trade data. The Bureau of the Census data do not indicate sufficient imports for consumption when compared to reported consumption data, consumer stocks, domestic shipments, and the Journal of Commerce Trade Information Service. Officially, the Republic of South Africa was the largest supplier of fluorspar to the United States, followed by, in descending order, China, Mexico, Spain, and Morocco. The average c.i.f. unit value, in dollars per metric ton, was \$144 for acid grade and about \$102 for subacid grade. If the missing shipments are added, China becomes the largest supplier, and the unit price for acid grade would be significantly lower. (See table 6.)

Imports for consumption of HF decreased 19% to a quantity equivalent to approximately 124,000 tons of fluorspar. Imports of synthetic and natural cryolite decreased 54% to a quantity equivalent to

approximately 4,030 tons of fluorspar. Imports of aluminum fluoride decreased by more than 6% to a quantity equivalent to approximately 50,000 tons of fluorspar. (See tables 7, 8 and 9.)

World Review

World fluorspar consumption and production decreased compared with 1990 levels. In order of rank, China, Mongolia, Mexico, the U.S.S.R., and the Republic of South Africa were the major producers. The international fluorspar industry experienced the continuing effects of major changes in traditional markets, such as fluorochemicals and steel. Many of the traditional producing countries saw significant decreases in fluorspar production in 1991, with Mexico being the hardest hit.

China.—Fluorspar exports from China continued at high levels, but decreased for the second straight year. Reported exports were 934 thousand tons in 1991, compared with 1.09 million tons in 1990 and 1.18 million tons in 1989. Based on reported export data and estimates of domestic consumption, it is estimated that China produced about 1.6 million tons in 1991. Although uncertainty exists concerning the level of domestic consumption in China, it is estimated that consumption levels have increased mainly for metallurgical grade. China's steel production has increased from 61 million tons to 71 million tons over the past 2 years.

Italy.—Fluorspar production in Italy continued to decline in 1991. Estimated 1991 production was 70,000 tons of acid grade and 30,000 tons of metallurgical grade. The largest producer was Mineraria Silius, S.p.A., which owns and operates an underground mining complex and a heavy-media plant adjacent to Cagliari, in southeastern Sardinia, and a flotation mill 17 kilometers west of Cagliari. In 1991, the Sardinian Regional Government increased its support of the company's operations, which include the mines, heavy-media plant and flotation

mill, and an aluminum fluoride-synthetic cryolite plant. Collectively, the mining complex has been renamed the Gerrei Mines, replacing the former Silius Mines designation.

Mexico.—Mexico's production dropped by more than 44% in 1990, as sales of both metallurgical grade and acid grade decreased. Process improvements and use of economical substitutes by the steel industry affected metspar sales. The CFC phaseout, U.S. recession, and price pressure from Chinese exports all adversely impacted Mexican production. These factors caused the shutdown of some mining units. Sesa Fluorspar, a new producer, operated the second half of 1990 and the first quarter of 1991. It shut down in 1991 primarily as a result of high freight costs. Fluorita de Rio Verde operated at full capacity in 1991 (7,500 tons per month), but their sales decreased, and they shut down "temporarily" at the end of 1991. The shutdown could be prolonged, but steps were taken to maintain operations to allow a restart if markets improve. Cia Minera La Valenciana SA planned to reopen its fluorspar mine in Torreón to supply feedstock for HF production. The company purchased the Essex-Dow HF plant from Paulsboro, NJ, and rebuilt it at Torreón. Plant output was scheduled to begin in the first quarter of 1992.

The Mexican fluorspar mining industry was hurt in 1991 by Chinese imports. As a result, the Mexican Chamber of Mines is preparing a countervailing duty investigation on Chinese fluorspar exports to Mexico. The investigation was initiated mainly at the request of the small producers.

Mongolia.⁶—Mongolia is the world's second largest producer of fluorspar. Table 10 shows revised production totals for 1987-90 and an estimate for 1991. Fluorspar is mined in east-central and southeast Mongolia, including the Chulut Cagan Del, Adag, Bor-Ondor, Hajuu-Ulaan, Zuun Cagan Del, Hamar-Uls, Orgon, Berh, Delgerhaan, and Har-Ayrag Mines.

Mongolia and the U.S.S.R. have had close ties since 1921 and have cooperated in mining ventures since after WWII. Soviet assistance provided mining technology, skilled labor, technicians, and substantial physical infrastructure. In return, the U.S.S.R. received relatively cheap raw materials. In the 1970's, the Soviet foreign trade association Tsvetmetpromexport promoted joint U.S.S.R.-Mongolian mining ventures, including the Mongolsovsvetmet Association, which operates a number of fluorspar and gold mines. A major fluorspar operation developed by Mongolsovsvetmet and the U.S.S.R. is the Bor-Ondor mine and mill complex in the extreme southwestern corner of Khentii Province. This complex consists of an underground mine and adjacent flotation mill, plus a 50-kilometer rail line connecting with the Trans-Mongolian railway at Tsagaandorolj. Mine production began in 1982, and mill production began in 1985. All of Mongolia's acid-grade fluorspar is produced at Bor-Ondor.

The changes in the U.S.S.R. and Eastern Europe have forced Mongolia to reform its economic, social, and political policies. The U.S.S.R. has accounted for 90% of Mongolia's foreign trade. The level of Soviet aid, both financial and technical, will be much reduced in the future. Mongolia needs to expand its trade and contact with the rest of the world to increase its return for exports, draw foreign investment, and replace the technical expertise lost when Soviet technicians depart.

To this end, the Mongolian President, Punsalmaagiyn Ochirbat, has initiated a policy promoting ties with nations outside the Soviet bloc. On January 23, 1991, the U.S. Trade Representative and the Mongolian Minister of Trade and Industry signed a trade agreement to improve economic and business ties between the two nations. The accord assigns each other most-favored-nation (MFN) status, with the corresponding MFN tariffs. Mongolia signed a similar agreement with Japan in 1990.

Namibia.—Okorusu Fluorspar Ltd. closed down its mine during November and December 1991 because production had been running ahead of contractual commitments and their storage facility in Walvis Bay was full. The time was used to perform maintenance work. Production was scheduled to start up again on schedule in January of 1992. Earlier technical problems have been overcome, and the mill was attaining the designed production rate of about 1,000 tons per week.

United Kingdom.—Fluorspar production is concentrated in Derbyshire, with production from Laporte Minerals, Weardale Minerals Ltd., Deepwood Mining Co. Ltd., Biwater Pipes Ltd., and Matlock Barytes Co. Ltd. Laporte Minerals is the largest acid-grade producer. Weardale Minerals Ltd. was part of the Minworth Group, which went into receivership in January 1991. It was sold to Sherburn Stone Co. Ltd. of Durham midyear 1991, which planned to continue operations at the Greenclough and Frazers Hush Mines. United Kingdom production was down 30,000 to 40,000 tons compared with that of 1990. (See table 10.)

Current Research

Sandia National Laboratories, Center for Solder Science and Technology, is developing "fluxless" soldering technologies. These technologies will not require the use of rosin-based fluxes, which traditionally have been removed after soldering through the use of CFC cleaning solvents. The research involves soldering technologies that use controlled atmospheres, protective coatings, and thermomechanical surface activation. Research has shown that in controlled atmosphere soldering, hydrogen plasma cleaning of heavily oxidized copper can produce oxide-free, solderable surfaces at temperatures below 250° C. Most electronic components cannot abide temperatures above 250° C. Additional research has been conducted on controlled atmosphere techniques, and the center is also investigating ultrasonic and laser

soldering processes.⁷ This research could result in lost markets for CFC solvents.

OUTLOOK

Consumption of metallurgical-grade fluorspar by the steel industry decreased dramatically in 1991. This was due in part to the overall drop in steel output, but it was mainly a reflection of the continuing change in technology, improvement in efficiencies, and tighter raw material specifications. Closure of open-hearth furnaces, which required significant quantities of fluorspar, reduces a traditional market for fluorspar. Other factors such as the introduction of bottom blown basic oxygen process furnaces, external desulfurization, and continuous casting have also aided the decline in fluorspar consumption. These technologies either do not need fluorspar, need greatly reduced quantities, or discourage its use to minimize refractory damage and downtime. The steel industry has been forced to modernize, increasing the efficiency of each stage of the steelmaking process and dictating tighter raw material specifications. The latter has led to lower impurity levels in the steel, and thus less need for fluorspar.

These factors indicate that U.S. consumption of metallurgical-grade fluorspar will continue to decrease through the 1990's. Major steel-producing countries are undergoing the same changes, and fluorspar consumption is also expected to decline in those countries. The U.S.S.R., China, and the Eastern bloc nations are farther behind on the modernization curve, but it is only a matter of time before modernization begins to lower fluorspar consumption to levels similar to those in Western Europe, North America, and Japan.

The aluminum industry consumes fluorine from different sources and in different forms. Although some acid-grade fluorspar is consumed directly, fluorine is also consumed in the form of aluminum fluoride and synthetic or natural cryolite. Aluminum fluoride is manufactured either directly from acid-grade fluorspar, from HF, or from

fluosilicic acid. A small amount of cryolite is imported for consumption, but most is recovered as a byproduct of waste fluorine recovery or, in the case of a new potline, by tapping an operating pot for molten electrolyte. This material, termed "molten crushed bath," is allowed to solidify and is then crushed for use in the startup of a new potline.

The domestic aluminum industry is expected to show slow steady growth over the next few years, but no expansion of capacity is anticipated. Although consumption of fluorspar by the aluminum industry decreased in 1991, as did imports of cryolite and aluminum fluoride, the consumption of fluorspar and fluorine chemicals by the aluminum industry is expected to remain at current levels or grow slowly.

Consumption of acid-grade fluorspar by the chemical industry for the production of HF is the largest market for fluorspar. The largest use of HF is in the manufacture of fluorocarbons (CFC's, HCFC's, and HFC's); the remainder is used in chemical intermediates, glass and metal processing, petroleum alkylation, stainless steel pickling, uranium chemical production, and other small uses. Consumption by the HF industry remained essentially unchanged in 1991. This was despite the continued decrease in CFC production. The loss in consumption for CFC production could have been taken up, at least in part, by production of HCFC and HFC replacement compounds. Growth in HF consumption for production of replacement HCFC's and HFC's could be slowed by increased recapture, purification, and recycling of CFC's. The EPA was required to publish regulations by July 1, 1992, establishing standards and requirements for the use and disposal of CFC's. These regulations will contain requirements that reduce the use and emission of CFC's and maximize the recapture and recycling of such substances. Although the regulations may contain requirements to use alternative substances, the requirement to recycle cannot help but boost the CFC recycling industry and thus possibly delay the conversion to replacement compounds

and technologies. In the short term, it appears that fluorspar consumption by the fluorocarbon industry will continue at much reduced levels from just a few years ago. Consumption should begin increasing by the mid-1990's, which is when the phase out of CFC production is to be complete and when domestic auto manufacturers will be switching over to the use of replacement compounds in auto air conditioners.

¹Kilgore, C. C., S. R. Kramer, and J. A. Bekkala. Fluorspar Availability—Market Economy Countries and China. BuMines IC 9060, 1985, pp. 16 and 17.

²Work cited in footnote 1.

³Department of Defense. 1992 Report to the Congress on National Defense Stockpile Requirements. Feb. 1992.

⁴U.S. Congress. Clean Air Act Amendments of 1990. Public Law 101-549, Nov. 15, 1990, 104 Stat. 2399.

⁵Environmental Protection Agency. Hydrogen Fluoride Study. Office of Solid Waste, Draft Report to Congress, Section 301(n)(6), Clean Air Act Amendments of 1990, May 8, 1992, 138 pp.

⁶Dorian, J. P. USSR-Mongolia: A Minerals Association About to End. Resources Policy, Mar. 1991, pp. 42-53.

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TABLE 1
SALIENT FLUORSPAR STATISTICS¹

		1987	1988	1989	1990	1991
United States:						
Production:						
Finished (shipments) ^a	metric tons	63,500	63,500	66,000	63,500	58,000
Value f.o.b. mine	thousands	W	W	W	W	W
Exports	metric tons	2,595	3,136	5,134	14,921	73,943
Value	thousands	\$308	\$346	\$694	\$1,891	\$16,424
Imports for consumption	metric tons	531,530	689,139	655,590	513,921	376,081
Value ²	thousands	\$43,935	\$62,748	\$79,897	\$65,938	\$46,182
Consumption (reported)	metric tons	542,830	651,055	641,882	564,545	483,589
Consumption (apparent) ³	do.	643,659	723,804	693,121	^r 566,885	365,831
Stocks, December 31:						
Domestic mines:						
Finished	do.	W	W	W	W	W
Consumer	do.	30,310	56,012	79,347	^r 74,692	68,999
World: Production	do.	^r 4,600,441	^r 5,086,376	^r 5,529,184	^r 5,024,626	^r 4,354,036

^aEstimated. ^rRevised. W Withheld to avoid disclosing company proprietary data.

¹Does not include fluosilicic acid (H₂SiF₆) or imports of hydrofluoric acid (HF) and cryolite.

²C.i.f. U.S. port.

³U.S. primary and secondary production plus imports minus exports plus adjustments for Government and industry stock changes.

TABLE 2
WORLD FLUORSPAR RESERVES AND RESERVE BASE¹

(Thousand metric tons contained CaF₂, 100% equivalent)

Country	Reserves ²	Reserve base ³
North America:		
United States	W	10,000
Canada	2,000	5,000
Mexico	19,000	23,000
Total	<u>21,000</u>	<u>38,000</u>
Europe:		
France	10,000	14,000
Italy	6,000	7,000
Spain	6,000	8,000
U.S.S.R.*	62,000	94,000
United Kingdom	2,000	3,000
Total	<u>86,000</u>	<u>126,000</u>
Africa:		
Kenya	2,000	3,000
Namibia	3,000	5,000
South Africa, Republic of	30,000	36,000
Total	<u>35,000</u>	<u>44,000</u>
Asia:		
China*	27,000	46,000
Mongolia*	50,000	59,000
Thailand	1,000	2,000
Total	<u>78,000</u>	<u>107,000</u>
Other countries	<u>19,000</u>	<u>25,000</u>
World total	<u>239,000</u>	<u>340,000</u>

*Estimated. W Withheld to avoid disclosing company proprietary data.

¹The definitions of reserves and reserve base are published in U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals," which is reprinted in the annual, U.S. Bureau of Mines, Mineral Commodity Summaries.

²Recoverable CaF₂ at the demonstrated level (measured plus indicated).

³The reserve base includes demonstrated resources, reported in terms of 100% CaF₂, that are currently economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).

TABLE 3
U.S. CONSUMPTION (REPORTED) OF FLUORSPAR, BY END USE

(Metric tons)

End use or product	Containing more than 97% calcium fluoride (CaF ₂)		Containing not more than 97% calcium fluoride (CaF ₂)		Total	
	1990	1991	1990	1991	1990	1991
	Hydrofluoric acid (HF)	324,275	328,696	—	—	324,275
Iron and steel (foundries)	—	—	3,336	W	3,336	4,077
Open-hearth furnaces	—	—	19,993	W	19,993	5,723
Basic oxygen furnaces	—	—	83,142	33,276	83,142	33,276
Electric furnaces	2,013	1,788	36,786	25,532	38,799	27,320
Other ¹	W	W	W	W	*95,000	84,497
Total	W	W	W	W	564,545	483,589
Stocks, December 31 (consumer)	*72,232	67,371	*2,460	1,628	*74,692	68,999

¹Estimated. *Revised. W Withheld to avoid disclosing company proprietary data; included in "Total."

¹Includes aluminum fluoride, glass and fiberglass, enamel, welding rod coatings, primary aluminum, and primary magnesium.

TABLE 4
PRICES OF DOMESTIC AND IMPORTED FLUORSPAR

(Dollars per metric ton)

	1990	1991
Domestic, f.o.b., Illinois district, bulk, acid grade	190 -195	190 -195
Chinese, dry bulk, c.i.f., Rotterdam, acid grade	NA	106 -110
Mexican, f.o.b., Tampico:		
Acid grade, filtercake	135	122 -127
Metallurgical grade	90 -95	90 -95
South African, f.o.b., Durban, acid grade, dry basis	130 -140	120 -125

NA Not available.

Source: Industrial Minerals (Metal Bulletin PLC), No. 280, Jan. 1991, p. 66 and No. 292, Jan. 1992, p. 62.

TABLE 5
U.S. EXPORTS OF FLUORSPAR, BY COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Australia	72	\$12,662	56	\$7,966
Canada	11,354	1,385,153	11,082	1,582,452
Colombia	55	6,200	25	2,820
Dominican Republic	637	155,398	3,427	524,577
Israel	254	27,983	—	—
Mexico	814	104,215	58,960	14,225,959
Taiwan	539	59,290	—	—
United Kingdom	545	60,099	102	11,421
Venezuela	651	79,666	291	68,337
Total	14,921	1,890,666	73,943	16,423,532

Source: Bureau of the Census.

TABLE 6
U.S. IMPORTS FOR CONSUMPTION OF FLUORSPAR, BY COUNTRY
AND CUSTOMS DISTRICT

Country and customs district	1990		1991	
	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)
CONTAINING MORE THAN 97% CALCIUM FLUORIDE (CaF₂)				
Brazil: Houston	5,433	\$354	—	—
Canada:				
Houston	6,360	753	—	—
New Orleans	15,777	2,433	—	—
Total	<u>22,137</u>	<u>3,186</u>	<u>—</u>	<u>—</u>
China:				
Houston	57,791	7,524	26,191	\$3,490
Laredo	—	—	—	—
New Orleans	67,397	8,920	48,662	5,470
Portland	2	6	—	—
Total	<u>125,190</u>	<u>16,450</u>	<u>74,853</u>	<u>8,960</u>
France:				
New York	54	51	—	—
Philadelphia	90	41	54	24
Total	<u>144</u>	<u>92</u>	<u>54</u>	<u>24</u>
Germany, Federal Republic of:				
Wilmington	6	12	—	—
Japan: New Orleans	—	—	4,627	416
Kenya: Houston	<u>8,800</u>	<u>1,234</u>	<u>—</u>	<u>—</u>
Mexico:				
Buffalo	949	106	—	—
El Paso	46,895	5,793	787	88
Houston	17,581	2,259	6,824	751
Laredo	63,306	8,386	55,254	7,027
New Orleans	13,531	1,609	7,457	857
San Diego	702	79	—	—
Total	<u>142,964</u>	<u>18,232</u>	<u>70,322</u>	<u>8,723</u>
Morocco: New Orleans	10,950	*1,533	9,828	1,382
Namibia: Houston	4,229	422	—	—
South Africa, Republic of:				
New Orleans	86,660	13,516	105,031	14,929
Spain: New Orleans	—	—	11,278	1,545
Grand total	<u>406,513</u>	<u>55,031</u>	<u>275,993</u>	<u>35,978</u>
CONTAINING NOT MORE THAN 97% CALCIUM FLUORIDE (CaF₂)				
Canada:				
Detroit	34	4	—	—
Seattle	—	—	285	22
Total	<u>34</u>	<u>4</u>	<u>285</u>	<u>22</u>
China: New Orleans	28,088	2,518	28,228	2,437
Japan: New Orleans	—	—	<u>4,674</u>	<u>387</u>
Mexico:				
Baltimore	5,699	641	—	—
Buffalo	325	30	50	6
Detroit	34	3	—	—
El Paso	17,153	1,171	3,789	209

See footnotes at end of table.

TABLE 6—Continued
**U.S. IMPORTS FOR CONSUMPTION OF FLUORSPAR, BY COUNTRY
 AND CUSTOMS DISTRICT**

Country and customs district	1990		1991	
	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)
Mexico—Continued:				
Houston	—	—	40	\$9
Laredo	683	\$65	1,914	295
New Orleans	41,265	4,529	42,484	4,460
Philadelphia	5,757	541	—	—
Seattle	90	158	1,264	88
Total	71,006	7,138	49,541	5,067
South Africa, Republic of:				
New Orleans	8,280	1,247	17,360	2,292
Grand total	107,408	10,907	100,088	10,204

¹Estimated.

¹C.i.f. value at U.S. port.

Source: Bureau of the Census.

TABLE 7
U.S. IMPORTS FOR CONSUMPTION OF HYDROFLUORIC ACID (HF), BY COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)
Canada	24,629	\$29,284	16,985	\$23,240
Germany, Federal Republic of	47	123	57	117
Japan	1,016	1,567	624	967
Mexico	75,362	77,513	64,464	64,471
United Kingdom	738	861	240	272
Total	101,792	109,348	82,370	89,067

¹C.i.f. value at U.S. port.

Source: Bureau of the Census.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF CRYOLITE, BY COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)
Australia	435	\$271	—	—
Canada	835	634	483	\$381
China	128	101	58	41
Denmark	2,335	2,314	1,328	1,588
Germany, Federal Republic of	874	720	742	728
Iceland	559	631	—	—
Japan	2,090	2,062	511	521
Netherlands	11	16	—	—
Other	39	26	237	189
Total	7,306	6,775	3,359	3,448

¹C.i.f. value at U.S. port.

Source: Bureau of the Census.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF ALUMINUM FLUORIDE, BY COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)
Canada	5,023	\$5,259	5,913	\$5,963
China	2,035	1,654	1,183	951
France	2,495	3,094	—	—
Italy	1,010	2,454	—	—
Japan	5,303	6,162	7,056	7,969
Mexico	16,712	18,961	15,546	15,513
Norway	1,999	2,061	2,674	2,506
United Kingdom	522	230	594	244
Other	505	420	360	278
Total	35,604	40,295	33,326	33,424

¹C.i.f. value at U.S. port.

Source: Bureau of the Census.

TABLE 10
FLUORSPAR: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ² and grade ³	1987	1988	1989	1990	1991 ⁴
Argentina	54,975	18,052	23,317	*20,000	20,000
Brazil (marketable):					
Acid grade	58,736	*54,920	56,973	*47,724	55,000
Metallurgical grade	31,212	*35,078	38,558	*22,659	35,000
Total	89,948	*89,998	95,531	*70,383	90,000
Canada: Acid grade ⁵	10,000	40,000	50,000	25,000	—
China: ⁶					
Acid grade	550,000	950,000	1,200,000	*1,150,000	1,000,000
Metallurgical grade	450,000	450,000	500,000	*550,000	600,000
Total	1,000,000	1,400,000	1,700,000	*1,700,000	1,600,000
Czechoslovakia	*95,000	*95,000	*68,910	*46,966	40,000
Egypt	776	1,849	1,721	*1,249	1,200
France:					
Acid and ceramic grades	134,000	153,000	159,000	*145,000	150,000
Metallurgical grade	*50,000	*50,000	*62,000	*56,000	50,000
Total ⁷	184,000	203,000	*221,000	*201,000	200,000
Germany:					
Eastern states ⁸	90,000	90,000	90,000	70,000	NA
Western states (marketable)	85,201	77,710	*73,770	*85,300	NA
Total ⁹	175,201	167,710	*163,770	*155,300	135,000
Greece ¹⁰	200	200	200	*200	200
India:					
Acid grade	8,259	8,823	10,300	*9,500	10,000
Metallurgical grade	4,450	6,772	12,589	*12,200	12,000
Total	12,709	15,595	22,889	*21,700	22,000
Iran ¹¹	*7,352	*6,483	*6,000	*4,767	6,000
Italy:					
Acid grade	77,800	81,700	66,600	*81,822	70,000
Metallurgical grade	56,600	58,157	59,679	*40,681	30,000
Total	134,400	139,857	126,279	*122,503	100,000
Kenya: Acid grade	61,504	99,092	95,181	*112,295	90,000
Korea, North: Metallurgical grade ¹²	40,000	40,000	40,000	40,000	41,000
Korea, Republic of: Metallurgical grade	63	261	856	*560	600
Mexico: ¹³					
Acid grade	409,846	338,000	359,000	*268,000	150,000
Ceramic grade	12,015	27,000	27,000	*11,000	5,000
Metallurgical grade	306,633	253,000	225,000	*192,000	107,000
Submetallurgical grade	95,398	138,000	168,000	*163,000	90,000
Total	823,892	756,000	779,000	*634,000	*352,000
Mongolia:					
Acid grade	73,000	115,000	115,000	119,000	120,000
Other grades ¹⁴	510,000	584,000	586,000	495,000	400,000
Total	*583,000	*699,000	*701,000	*614,000	520,000
Morocco: Acid grade	78,000	100,500	105,000	*86,500	86,000
Namibia: Acid grade	—	*1,500	*15,000	*25,980	*29,246
Pakistan	3,528	284	4,741	*5,312	5,300
Romania: Metallurgical grade ¹⁵	18,000	18,000	16,000	15,000	14,000

See footnotes at end of table.

TABLE 10-Continued
FLUORSPAR: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ² and grade ³	1987	1988	1989	1990	1991 ⁴
South Africa, Republic of:					
Acid grade ⁵	279,000	² 282,986	310,000	262,000	240,000
Ceramic grade ⁵	7,000	8,000	9,000	7,500	6,000
Metallurgical grade ⁵	30,606	37,435	49,340	41,532	24,340
Total	316,606	328,421	368,340	311,032	²270,340
Spain:					
Acid grade	147,757	137,140	¹ 154,493	² 95,000	85,000
Metallurgical grade	23,859	5,435	⁶ 6,799	⁵ 5,000	5,000
Total	171,616	142,575	¹161,292	²100,000	90,000
Sweden	220	225	¹ 150	¹ 150	150
Thailand: Metallurgical grade	102,398	76,321	98,375	⁹ 94,757	100,000
Tunisia: Acid grade	32,653	55,416	53,575	⁴ 40,974	40,000
Turkey: Metallurgical grade ⁶	10,000	⁴ 13,240	13,000	13,000	13,000
U.S.S.R. ⁷	410,500	410,500	410,000	380,000	350,000
United Kingdom	120,400	103,797	122,057	¹ 118,498	80,000
United States (shipments) ⁸	63,500	63,500	66,000	63,500	58,000
Grand total	⁴4,600,441	⁵5,086,376	⁵5,529,184	⁵5,024,626	4,354,036

¹Estimated. ²Revised. NA Not available.

³Table includes data available through May 18, 1992.

⁴In addition to the countries listed, Bulgaria is believed to have produced fluor spar in the past, but production is not officially reported, and available information is inadequate for the formulation of reliable estimates of output levels.

⁵An effort has been made to subdivide production of all countries by grade (acid, ceramic, and metallurgical). Where this information is not available in official reports of the subject country, the data have been entered without qualifying notes.

⁶Reported figure.

⁷Year beginning Mar. 21 of that stated.

⁸Data for 1987 were provided by the Instituto Mexicano de la Fluorita (now disestablished). Data since 1988 are as reported by Consejo de Recursos Minerales.

⁹Principally submetallurgical-grade material.

GALLIUM

By Deborah A. Kramer

Ms. Kramer is a physical scientist with the Branch of Industrial Minerals and has covered gallium for 8 years. Domestic survey data were prepared by Susan Copeland, statistical assistant.

No domestic gallium production was reported in 1991. Imports continued to supply essentially the total U.S. demand. France and the Federal Republic of Germany were the principal import sources, accounting for 81% of the total.

Most of the U.S. gallium demand was for gallium arsenide (GaAs) semiconductors used in optoelectronic devices and integrated circuits. More than 70% of the gallium consumed in 1991 was used in optoelectronic devices—light-emitting diodes, laser diodes, photodetectors, and solar cells. Demand increased somewhat from that of 1990, mostly because of an increase in production of integrated circuits.

World production of gallium was estimated to be about the same as that in 1990, with most of the purified gallium produced in France and the Federal Republic of Germany. The largest gallium recovery plant in the world in Australia remained closed during the year; the operators were purifying gallium from material that was stockpiled earlier.

Gallium demand in the United States is expected to increase slowly as the country emerges from the recent recession. One of the most promising applications of gallium is in GaAs-base visible laser diodes in barcode scanners. If these replace helium-neon lasers in this application, gallium consumption could increase at a faster rate.

DOMESTIC DATA COVERAGE

Gallium data are collected from two voluntary surveys of U.S. operations. In 1991, there were 33 responses to the "Consumption of Gallium" survey, representing 92% of the total canvassed.

Significant quantities of gallium are used by universities and Government research facilities, which are not canvassed by the Bureau's survey. Data in tables 1, 2, and 3 representing gallium consumption were adjusted to reflect full industry coverage. (See table 1.)

ANNUAL REVIEW

Production

No production of primary gallium was reported in 1991. Hecla Mining Co.'s operation in St. George, UT, remained closed throughout the year.

Eagle-Picher Industries Inc. recovered and refined gallium from both domestic and imported sources at its plant in Quapaw, OK. Recapture Metals Inc., Blanding, UT, recovered gallium from scrap materials, predominantly scrap generated during the production of GaAs.

Consumption and Uses

An increase in gallium demand in the United States in 1991 primarily resulted from an increase in GaAs-base integrated circuit production, although optoelectronic devices still represent the largest sector of gallium use.

TriQuint Semiconductor Corp., Beaverton, OR, reportedly purchased GaAs manufacturer Gigabit Logic Inc., Newbury Park, CA, and GaAs-base device manufacturer Gazelle Microcircuits Inc., Santa Clara, CA. TriQuint, also a GaAs manufacturer, closed Gigabit's facility in Newbury Park and continued to operate out of its Oregon facilities.

Spire Corp. received a contract from the National Aeronautics and Space

Administration (NASA) to continue development of high-power, multiple-quantum-well aluminum gallium arsenide (AlGaAs)-GaAs laser diodes. These diodes, which operate in the 780-nanometer spectral range, are used for pumping other lasers that operate at 2.09 micrometers. This 2.09-micrometer emission is used in systems that are capable of detecting wind shear and microbursts near airports. Wind shears and microbursts were cited as the causes for at least one aircraft crash in recent years. Spire is developing low-cost fabrication and packaging methods that will make the diode-laser pumps widely available.

Spire also received a contract from the U.S. Army's Strategic Defense Command to develop low-defect-density GaAs on patterned silicon. This work was expected to permit integration of GaAs and silicon, combining the high-speed and/or optical communications properties of GaAs with very-large-scale integration technology that is available with silicon.

In a review of laser-diode technology, recent advances in various categories of laser diodes were discussed. AlGaAs laser diodes, which operate in the range from 750 to 860 nanometers, are the largest volume manufactured annually and are used primarily in compact-disk players and laser printers. Indium gallium arsenide phosphide (InGaAsP) diodes lase from 1,300 to 1,600 nanometers and are used principally in fiber-optic communications systems, with expected potential in fiber sensors. Indium gallium arsenide (InGaAs) lasers operate from 910 to 990 nanometers and are used in erbium-doped fiber amplifiers. The indium gallium aluminum phosphide (InGaAlP) laser

diode emits at 630 to 680 nanometers and is also known as the visible laser diode. Recently developed, the InGaAlP diode has the potential to replace helium-neon lasers in barcode scanners.¹

Manufacturing methods and development of new devices were highlighted in other reviews of the GaAs-based laser diode industry. Development of manufacturing techniques, such as metal-organic vapor deposition technology and molecular beam epitaxy (MBE), have enabled the development of multiple-quantum-well structures, strained superlattice structures, and surface-emitting laser diodes. These advances in laser diode technology have aided the emergence of visible laser diodes and improvements in InGaAsP lasers used in fiber-optic communications systems.² (See tables 2 and 3.)

Markets and Prices

Quoted prices, as published in American Metal Market, did not change during 1991. Beginning in January 1992, Eagle-Picher's quoted price for 99.99999%-pure gallium was expected to decrease from \$525 per kilogram to \$425 per kilogram. Prices for 99.9999%-pure gallium were scheduled to decrease to \$350 per kilogram. The average value of U.S. imports in 1991 was \$340 per kilogram, a slight increase from that in 1990; this value includes imports of both crude and high-purity gallium. (See table 4.)

Foreign Trade

Export data for gallium were not separately identified by the Bureau of the Census. According to the Journal of Commerce Port Import/Export Reporting Service (PIERS), 530 kilograms of gallium was exported, primarily to France. In addition, 292 kilograms (gross weight) of gallium arsenide scrap was exported to France. This source provides data only on materials that are transported by ship and may not reflect the total quantity of gallium exported.

Beginning in 1991, the Bureau of the Census began reporting data on imports

of GaAs wafers into the United States. In 1991, 2,186 undoped GaAs wafers, with a value of \$2.4 million, were imported. Japan (58%) and the Federal Republic of Germany (36%) were the primary source countries. The United States also imported 62,036 doped GaAs wafers at a value of \$39.1 million. Again, Japan (76%) and the Federal Republic of Germany (13%) were the main sources. (See table 5.)

World Review

Virgin gallium production was estimated to be about 40,000 kilograms in 1991. Although gallium demand did increase slightly in the United States, increased gallium recycling in Japan satisfied a significant portion of the country's demand. China has become a significant supplier of crude gallium in the past year, particularly to the Japanese market, but France and the Federal Republic of Germany remained the largest world suppliers of purified gallium. Rhône-Poulenc S.A.'s gallium recovery plant in Australia remained closed throughout the year, and the company continued to supply purified gallium from material stockpiled at the plant during its operation in 1989 and 1990. (See table 6.)

Germany, Federal Republic of.—In April, Wacker Chemitronic GmbH announced that the company planned to stop production of GaAs wafers and concentrate on silicon wafer technology. Wacker cited limited European demand and Japanese dumping as reasons for discontinuing production of GaAs wafers. The company was the Federal Republic of Germany's only commercial producer of GaAs wafers.

Japan.—Gallium imports into Japan were estimated at almost 30,000 kilograms, compared with 1990 imports of 20,314 kilograms. These imports supplied more than 40% of Japan's total gallium demand in 1991, estimated to be 70,000 kilograms, which includes recycled gallium scrap. The large

increase in imports from 1990-91 reflected an increase in imports of crude gallium, particularly from China. Japan's gallium demand was estimated to be concentrated in GaAs large-scale integrated circuits and optical devices, such as light-emitting diodes.³

Dowa Mining Co. Ltd., who developed gallium-base waxes for skis in 1990, planned to introduce new skis bonded with a sheet of gallium ethylene in early 1992. The sheet is formed by sintering a mixture of gallium powder and ethylene, and Dowa claimed that skis equipped with the sheet will be antistatic and would enable skiers to slide on any kind of snow. Alpine skis, marketed under the ULLR Racing name, will retail for about \$1,000, and cross-country skis will cost about \$554.

U.S.S.R.—Primary gallium production capacity was estimated to be 30,000 kilograms from four plants. In 1990, production was estimated at 16,000 kilograms. Demand in the U.S.S.R. was estimated to be 3,000 to 5,000 kilograms for defense applications and 2,000 to 3,000 kilograms for other applications. The U.S.S.R. reported that its product is from 99.99% to 99.99999% pure, but consumers in Japan rate the material at 99.99% purity. Because of the radical changes in the U.S.S.R., some of the gallium is appearing on the world market. Japan reportedly imported 1,300 kilograms in 1991, a significant increase from the 50 kilograms reported in 1990.⁴

Current Research

Scientists at Georgia Tech developed a small-scale process that could make the manufacturing of low-cost integrated optoelectronic circuits possible. The scientists grew GaAs devices on a GaAs substrate, peeled them off the substrate, then transferred them to a transparent polyimide sheet, which is used to align the GaAs devices on a silicon substrate. The peeling technique was originally developed at American Telegraph & Telephone Co.'s (AT&T) Bell Communications Research Center, but the Georgia Tech team modified the process

to address manufacturing and cost issues. Combining GaAs components and silicon components on a single integrated circuit allows the use of some GaAs properties that silicon does not have, such as light emission, while minimizing the cost. Integrated optoelectronics are important in the next generation of consumer electronics, such as videophones and high-definition television.

IBM Corp.'s European research laboratory developed a method to mass-produce and test as many as 20,000 semiconductor lasers on 1 GaAs wafer. IBM expects this new method of laser fabrication, which it calls full-wafer technology, to be faster, about 50% less expensive, and result in a higher percentage of working lasers per wafer. In the new technology, IBM used a process to etch small trenches in 2-inch-diameter wafers of laser material. Then it covered the trenches with a reflective material to turn them into mirrors. After testing the entire wafer, it was cut into 20,000 individual lasers. Current laser making methods form mirrors by breaking the wafer into tiny pieces first; the broken edges act as mirrors. Each device must then be tested one at a time. Semiconductor lasers are used in devices such as compact-disk players and laser printers.⁵

Toshiba Corp. demonstrated a visible laser diode made from indium gallium aluminum arsenide (InGaAlAs) that has the shortest wavelength of any diode currently available—650 nanometers. The company claimed that the InGaAlAs diode would produce light that is four times as bright as other commercially available laser diodes. Applications for the new laser diode include barcode scanners, which use primarily helium-neon lasers that emit light at 670 nanometers.

Using new metal-organic vapor deposition technology, Sanyo Corp. produced a bright red InGaAlP laser diode that operates at 635 nanometers for read-only applications. The emitting wavelength was shortened, and the brightness increased by misorienting the GaAs substrate. The shorter operating wavelength resulted in a smaller beam

contact, which should enable higher density in encoding optical disks. According to Sanyo, the density of write-to-disk data is 50% greater than currently available. This would allow 90 minutes of programming on a compact disk that normally contains 60 minutes and would increase the dot-per-inch output of laser printers from 300 to 370.⁶

Nissin Electric Co. Ltd. reportedly developed an MBE device that makes compound semiconductors using gaseous raw materials rather than the solid raw material used by conventional MBE systems.

In conventional MBE operations, solid raw materials must be supplied by opening doors in the equipment and requires batch operating processes. In Nissin's gaseous system, the material is drawn through a pipe, allowing for continuous operation. Nissin planned to sell the new equipment for slightly less than \$1 million.

Two separate studies on gallium demonstrated that gallium was a potential candidate in some superconducting materials. Researchers at Northwestern University formed a new family of superconducting compounds containing copper, gallium, and oxygen. The new material, which becomes superconducting at 73° K, is the first to conduct electricity along the planes formed by copper and oxygen atoms when they are separated by nonconducting chains of atoms. The use of copper and gallium reportedly forms a unique spacing structure between the copper-oxygen planes, which gives the superconductor better thermal and mechanical stability.

A team of scientists from Lawrence Berkeley Laboratory and the University of Warsaw in Poland demonstrated that GaAs that contains a little extra arsenic can conduct electricity with little or no resistance at 10° K. By adding additional quantities of arsenic during low-temperature growth of GaAs by MBE, scientists were able to create "islands" of pure arsenic in the compound. Earlier, scientists at the Massachusetts Institute of Technology had demonstrated that GaAs could be made insulating with the incorporation of additional arsenic. Although superconductivity research is in

its early stages, in the future, scientists hope to manipulate GaAs so that parts of the material are superconducting, parts are semiconducting, and parts are insulating.

Scientists were still pushing the limits of silicon technology, potentially allowing silicon to compete in areas that were thought to be better suited for GaAs. Two separate organizations reportedly developed methods to make silicon emit light—one of the properties that separates GaAs semiconductors from silicon semiconductors. Researchers at AT&T's Bell Laboratories duplicated efforts by British scientists in producing silicon that emits red light when green light from a laser is shone on it. The British researchers created what they called porous silicon, which was created by using acid to etch small holes in the silicon. This process created thin wirelike structures that have optical properties different from those of normal silicon. Although this represents an advance in silicon technology, it is still in the early stages of development. Porous silicon may be unstable in air, and scientists must find ways to use electrons rather than lasers to induce silicon to emit light before the material can be considered a serious candidate for light-emitting applications.⁷

At the University of Electro-Communications in Japan, professors reportedly generated orange light using grains of silicon. In an experiment, silicon powder with a diameter of about 1 micrometer was placed on a silicon substrate and heated to 2,000° C in an argon-oxygen atmosphere until silicon grains about 1 Angstrom formed, oxidized, and attached themselves to the substrate. Green laser light was focused on these grains, and orange light was created through photoluminescence.

Hitachi Manufacturing Co. Ltd. announced the development of a prototype silicon transistor that has the high speed of a GaAs transistor and operates at lower temperatures than conventional silicon transistors. Two of GaAs's advantages over silicon are its faster speed and ability to operate over a wider temperature range. The new

silicon device, if commercially feasible, could lessen the impact of GaAs components in some markets.

OUTLOOK

Nearly all the gallium consumed in the United States is used in manufacturing GaAs-base optoelectronic devices and integrated circuits. Much of the work in producing new devices and improving manufacturing techniques is funded, either directly or indirectly, by the U.S. Department of Defense. As Defense budgets undergo continued scrutiny and cuts in funding are made, it is possible that some of the GaAs integrated circuit research and development activities are scaled back or terminated. With slower advancements in technology, GaAs integrated circuits will be slow to enter the commercial market. At the same time, private industry and universities are funding some research and development activities on GaAs. If these efforts can offset some of the anticipated defense cutbacks, GaAs consumption for integrated circuits in the United States should grow, although slowly.

Advances in silicon technology may limit the penetration of GaAs into some applications, primarily because of the cost of GaAs components compared to the cost of silicon components. But GaAs optoelectronic components are competing with materials other than silicon. In particular, GaAs visible laser diodes are competing with helium-neon lasers in barcode scanning applications. To aid in getting a share of this market, GaAs manufacturing firms are developing new manufacturing technologies that improve performance characteristics while lowering the cost of GaAs visible laser diodes. This application for GaAs components has a significant potential for growth. Overall, it is likely that U.S. gallium consumption will grow slowly in the next few years.

World supply patterns for gallium may change in the next few years. With the breakup of the U.S.S.R. into independent States and the downplaying of the country's defense industry, it is likely that some of the gallium produced

in the independent States will be available on the world market. Even in 1991, Japan was seeing greater availability of Soviet gallium, although the material is not high purity. China and the independent States may provide a significant share of gallium demand in Japan at the expense of France and the Federal Republic of Germany. It is unlikely that Soviet material will have an immediate impact on the U.S. supply because of the high tariff rate on gallium; the U.S.S.R. still has non-most-favored-nation status. This may change if the independent States are granted most-favored-nation status.

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⁴Roskill's Letter From Japan. No. 190, Feb. 1992, pp. 2-3.

⁵_____. No. 182, June 1991, pp. 5-8.

⁶IBM Finds Way To Reduce Costs of Small Lasers. *The Wall St. J.*, v. 217, No. 22, Jan. 31, 1991, p. B4.

⁷Kaplan, H. Semiconductor Lasers: Expanding the Frontiers. *Photonics Spectra*, v. 25, No. 9, Sept. 1991, pp. 70-72.

⁸Stipp, D. Scientists Find Silicon Emits Laser's Light. *The Wall St. J.*, v. 217, No. 86, May 2, 1991, p. B4.

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TABLE 1
SALIENT U.S. GALLIUM STATISTICS

(Kilograms unless otherwise specified)

	1987	1988	1989	1990	1991
Production*	W	—	—	—	—
Imports for consumption	12,490	12,160	15,284	9,894	11,271
Consumption	10,729	10,741	9,667	9,860	11,238
Price per kilogram	\$525	\$525	\$525	\$525	\$525

*Estimated. W Withheld to avoid disclosing company proprietary data.

TABLE 2
U.S. CONSUMPTION OF
GALLIUM,¹ BY END USE

(Kilograms)

End use	1990	1991
Optoelectronic devices:		
Laser diodes and light-emitting diodes	5,251	5,553
Photodetectors and solar cells	703	2,451
Integrated circuits:		
Analog	1,317	2,013
Digital	372	528
Research and development	846	229
Other	1,371	464
Total	9,860	11,238

¹Includes gallium metal and gallium compounds.

TABLE 4
YEAREND GALLIUM PRICES

(Dollars per kilogram)

Gallium metal, 99.99999%-pure, 100-kilogram lots	525
Gallium metal, 99.99%-pure, 100-kilogram lots	435
Gallium metal, 99.9999%-pure, imported	460 - 490
Gallium oxide, 99.99%-pure	435
Gallium oxide, 99.99%-pure, imported	400 - 420

Source: American Metal Market.

TABLE 3
STOCKS, RECEIPTS, AND CONSUMPTION OF GALLIUM,¹ BY GRADE

(Kilograms)

Purity	Beginning stocks	Receipts	Consumption	Ending stocks
1990:				
97.0% to 99.9%	23	3	14	12
99.99% to 99.999%	10	30	19	21
99.9999%	354	6,490	6,625	219
99.99999%	220	3,295	3,202	313
Total	607	9,818	9,860	565
1991:				
97.0% to 99.9%	12	—	—	12
99.99% to 99.999%	21	25	7	39
99.9999%	219	8,281	8,236	264
99.99999%	313	2,927	2,995	245
Total	565	11,233	11,238	560

¹Revised.

¹Consumers only.

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF GALLIUM
(UNWROUGHT, WASTE AND SCRAP), BY COUNTRY

Country	1990		1991	
	Kilograms	Value	Kilograms	Value
Belgium	32	\$3,200	—	—
Bulgaria	—	—	45	\$5,400
Canada	—	—	666	128,183
China	437	73,411	50	5,400
Czechoslovakia	—	—	20	2,800
France	3,994	1,429,381	5,266	1,990,002
Germany, Federal Republic of	3,265	1,160,842	3,890	1,140,898
Hungary	310	59,425	100	30,530
Japan	339	195,309	474	357,245
Norway	1,000	215,000	—	—
Singapore	—	—	20	4,600
Taiwan	—	—	22	21,787
U.S.S.R.	—	—	1	2,500
United Kingdom	517	113,334	717	139,670
Total	9,894	3,249,902	11,271	3,829,015

Source: Bureau of the Census.

TABLE 6
WORLD ANNUAL
PRIMARY GALLIUM
PRODUCTION CAPACITY,¹
DECEMBER 31, 1991

(Metric tons)

Country	Rated capacity
North America: United States ²	3
Europe:	
Czechoslovakia	3
France	20
Germany	20
Hungary	4
U.S.S.R.*	30
Total	77
Asia:	
China	8
Japan	7
Total	15
Oceania: Australia	50
World total	145

*Estimated.

¹Includes capacity at operating plants as well as at plants on standby basis.

²All U.S. capacity is standby capacity as of Dec. 31, 1991.

GEMSTONES

By Gordon T. Austin

Mr. Austin, a physical scientist with more than 30 years industry and Government experience, has been the gemstones commodity specialist since 1986. Mr. William Field, statistical assistant, prepared the domestic production survey data.

Webster's defines a gem "as any jewel, whether stone, pearl or the like, having value and beauty that are intrinsic and not derived from its setting; a precious or, sometimes, a semiprecious stone cut and polished for ornament. A stone of value because it is carved or engraved, as a cameo or intaglio." Additionally, the dictionary states that gemstone or gem material is a stone or material from which a gem may be cut. In less formal or common terms a gem, gemstone, or gem material may be described as specimens of minerals or organic materials used for personal adornment, display, or to manufacture objects of art because they possess beauty, rarity, and durability.

In 1991, the value of natural gemstones from deposit in the United States was \$84.4 million, an increase of 60% compared with that of 1990. Production of gemstones included faceting rough, lapidary rough, carving material, specimen material, natural and cultured freshwater pearls, mother of pearl, fossil ivory, amber, agatized coral, and coral.

Synthetic gemstones are grown in the laboratory but have essentially the same appearance, and optical, physical, and chemical properties as the natural material that they represent. Synthetic gemstones produced in the United States include alexandrite, coral, diamond, emerald, garnet, lapis lazuli, quartz, ruby, sapphire, spinel, and turquoise. Simulants are laboratory grown gem materials that have an appearance similar to that of a natural gem material but have different optical, physical, and chemical properties. The gemstone simulants produced in the United States include coral, cubic zirconia, lapis lazuli,

malachite, and turquoise. Additionally, certain colors of synthetic sapphire and spinel, used to represent other gemstones, would be classed as simulants. Colored and colorless varieties of cubic zirconia are the major simulants produced. In 1991, the reported combined production value of U.S. synthetic and simulant materials was \$17.9 million, about a 17% decrease from that of 1990.

Wholesale and retail outlets, gem and mineral shops, gem and mineral shows dealers, cutting factories, and jewelry manufacturers were the major purchasers of domestic gem materials.

DOMESTIC DATA COVERAGE

The U.S. Bureau of Mines estimates U.S. production from the "Natural and Synthetic Gem Material Survey," a voluntary survey of U.S. operations, and from Bureau estimates of unreported production. Of the approximately 400 operations surveyed, 82% responded, accounting for about 95% of the total production, 92% of the natural production, and 100% of the synthetic and simulant production.

The number of operations surveyed in 1991 was essentially the same as the number surveyed in 1990. The response rate was essentially the same also. The Bureau estimated the production by nonresponding operations, by professional collectors, and by amateur or hobbyist collectors. The basis for these estimates were information from published data, conversations with gem and mineral dealers, analyses of gem and mineral shows and sales statistics, and from information informally supplied by collectors. In the formal voluntary

survey and the informal surveys, the Bureau is totally dependent upon the cooperation of the producers, brokers, dealers, and collectors. Individuals and companies have been very cooperative and forthcoming with information. The Bureau is very appreciative of this cooperation.

BACKGROUND

The history of production and preparation of gemstones begins with the wearing of items for personal adornment in prehistoric times; this preceded even the wearing of clothes. Amber was mined in the Baltic countries for use as a gem material before 25,000 B.C. Later, the Phoenicians in their writings described their trade routes to the Baltic for amber and to areas in Asia and Africa for other gemstones. The voyages of Columbus brought increased interest in gemstone deposits, especially emerald, in South America. The discovery of diamond in Africa in 1859 focused major interest on Africa. More recently, the discovery of diamond in Western Australia in 1967 resulted in the development of the largest known diamond deposit in the world.

Commercial mining of gemstones has never been extensive in the United States. Although more than 60 different gem materials have been produced commercially from domestic sources, most of the deposits are relatively small. In many instances, production rests in the hands of the numerous hobbyists and members of mineralogical and lapidary clubs. The Crater of Diamonds State Park near Murfreesboro, AR, is open to the public on a daily fee basis, as are

many other gemstone deposits throughout the United States. Many gem-quality stones are found at these locations each year.

Definitions, Grades, and Specifications

Select rocks, certain varieties of mineral specimens, and some organic materials, such as pearl, amber, jet, and coral, are included in gemstones data. Customarily, diamond, ruby, sapphire, and emerald are considered the major gems.

The most important qualities of gemstones are beauty, durability, uniqueness, and rarity. Beauty, indicated as splendor, purity, or attractiveness, is judged mainly according to the taste of the beholder, and includes such appearances as luster, transparency, brilliance, and color. Luster of a mineral or stone is independent of color and is the surface appearance in reflected light. Apart from materials that have a metallic luster, the chief contributors to luster are transparency and refractive index. In cut gems, the perfection of the polish enhances the luster. Visible imperfections impair the luster of transparent stones. However, defects, described as "jardens" or "inclusions," may enhance the beauty and value of natural rubies, sapphires, and other gemstones. In some cases these inclusions may be used to identify the country and even the mine from which the stone was recovered. Durability is measured by the resistance of a stone to abrasion, pitting, chipping, or splitting. Resistance to abrasion is correlated with relative hardness, but intrinsic brittleness and toughness indicate resistance to wear in other aspects. Rarity is an essential qualification and is more important for some stones in determining their value than their physical characteristics.

Of the approximate 2,700 mineral species, only about 100 possess all of the attributes required of a gem. It must be noted that collectors of gems may not require that a gem be durable because the stone is destined for display and is not to be worn. Therefore, the number of

species of gemstones may be greater than the 100 that meet all of the requirements. Silicates furnish the greatest number, including such minerals as beryl, topaz, tourmaline, and feldspar. Oxides such as corundum (ruby and sapphire) and quartz (amethyst, agate, etc.) comprise the second largest group. Sulfides, carbonates, and sulfates are of small importance; the phosphates yield only turquoise and variscite. An exception is pearl, essentially calcium carbonate, which is ranked high as a gem. Diamond, the best known gem, is an isometric crystalline form of the element carbon.

In general, gemstones are classified the same as minerals; that is, into group, species, and variety. Group refers to two or more gem materials that are similar in crystal structure and physical properties but have different chemical properties. Each individual member of the group is called a species. Varieties of species have similar crystal structure and chemical characteristics but differ in color. An example of this would be the hessonite variety of the grossular species of the garnet group.

Products for Trade and Industry

Cutting and polishing of gems from gemstones are done to obtain the most effective display of the material. No significant change is made in the fundamental properties, and the preparation is intended to enhance the desirable characteristics that are present initially. Gemstones are cut into gems in three main styles: cabochons, baroque, and faceted.

Cabochons are cut in four operations: sawing, grinding, sanding, and polishing. Sawing, the initial step in cutting, is customarily done with a diamond saw to obtain a slab or slice of the desired size and thickness from the rough gemstone. The cabochon outline is scribed onto a flat surface, most often using a template for making a standard size for jewelry mountings. Rough grinding of the stone may be by metal-bond diamond, electroplated diamond, silicon carbide, or aluminum oxide wheels or coated

abrasive disks. In grinding, the hardness of the gemstone determines the grit and hardness of the abrasive used. Multiple grinding steps starting with 80- to 100-mesh (grit) through 600-mesh abrasives are normally used. The scratches left by grinding are removed by progressively finer grinding and sanding. Disk or belt sanders use bonded to cloth abrasives, waterproof reinforced paper abrasives, or cloth charged with abrasive pastes. The final polish is obtained by using hard felt, wood, or leather laps, with various polishing agents such as fine diamond compound, tin oxide, tripoli, chromium oxide, cerium oxide, alumina, or rouge.

Polished irregular shapes are called baroque gems. An inexpensive method of polishing baroque gems is to tumble them in rubber-lined drums, using a grinding and polishing medium with or without water.

Facet cutting usually is employed on transparent gemstones to increase brilliancy and appearance. It generally is confined to the harder materials. Softer materials may be faceted, but extreme care must be exercised in cutting and polishing the stones and in their use in jewelry. Often the softer gems are used only for display and not for making jewelry. The "round brilliant" cut, most commonly used in faceting, has 58 facets, 33 above the circle "girdle" and 25 below it, arranged in eightfold symmetry. The "round brilliant" and some other common cuts are illustrated in figure 1.

Industry Structure

The world market for rough diamonds is controlled to a degree by De Beers Centenary AG's marketing arm, the Central Sales Organization (CSO). It is by far the most controlled of the world's commodity markets. An estimated 80% to 85% of gem and natural industrial diamond is marketed by the CSO. The marketing is done through the CSO by the Diamond Trading Co. Ltd. and the Industrial Distributors Ltd. The CSO sells uncut gem diamonds on behalf of De Beers and most other major producers at sights (approved bidder viewings) in London, England, and Lucerne,

Switzerland. There are 10 such sights each year.

Diamonds reach the CSO sights through three channels. De Beers owned and operated mines, contracts sales by mine owner and operators, and open-market competitive sales. The distribution of rough diamonds in the Republic of South Africa is determined by the South Africa Diamond Board. All categories of rough diamonds that can be processed economically in South Africa must first be offered to local manufacturers. Rough can be exported duty free only if it has first been offered to the local market, otherwise a 15% duty is charged. Different systems of offering rough on the local market apply to the different mine producers, but they must offer the rough to local manufacturers in a manner determined by the board.

The CSO has been extremely successful at maintaining the rough diamond market for about 50 years. In modern times there has never been a decrease in CSO's price of rough diamonds. Table 1 illustrates the timing and the amounts of the average CSO price increases for rough gem diamonds from 1949 until the present, while table 2 indicates the value of CSO's annual sales for the past 10 years. The compounded effect over 43 years of these increases is a price increase of about 1,800%. Thus, a piece of rough that sold for \$100 in August 1949 would sell for about \$1,800 in April 1991. (See tables 1 and 2.)

For more than 30 years, the major diamond cutting and polishing centers of the world were in Belgium and Israel, with a certain amount of the larger stones being cut in the United States. However, in the early 1980's, the development of a large cottage industry in India—today there is estimated to be more than 500,000 cutters—made a major impact on world diamond trade. India consumes most of the world's small-gem, cheap-gem, and near-gem rough material in the manufacture of small stones, which resulted in annual cut-stone exports worth billions of dollars. These small stones averaged less than one-fifth of a carat (0.20 carat). The availability of small inexpensive stones resulted in substantial

changes in the design of jewelry. The utilization of small cut diamond stones (usually 0.07 to 0.14 carats each, called *melee*) to create a *pavé* effect (set close together to conceal the metal base) is but one example. Cutting and polishing of colored, synthetic, and simulant gemstones is centered in Thailand, India, Hong Kong, Korea, China, and Brazil, where cheap labor and favorable export laws ensure the lowest total costs for finished gems. It is estimated that the U.S.S.R.'s diamond cutting industry employs about 16,000 workers. The eight *Krystall* factories at Moscow, Smolensk, Kiev, Barnaul, Vinnitsa, Yerevan, Kusa, and Gomel employ fewer than 8,000, with the Moscow plant having about 900 workers. The workers at the various factories may be paid by different methods.

The workers at the Moscow plant are paid by the piece according to its size and difficulty of the cut. At Kiev, those workers whose work is not subject to inspection receive a 50% higher salary. Some of the *Krystall* factories have an incentive program for workers producing stones of 0.3 carats and larger. The incentive is a bonus of 5% of the added value that is paid to each 20-worker team that is shared by the team.

Annual cut diamond production is a function of the number of workers in the industry and their productivity. If it is assumed that the industry has a production rate of 20 carats of finished goods per month per worker and that polished yields are less than 40%, then the industry's consumption of rough and yield of finished goods can be estimated. It is estimated that during a year, the U.S.S.R.'s diamond cutting industry processes about 3.8 million carats of rough that yields about 1.6 million carats of polished goods. The polished goods would be worth between \$500 million and \$550 million on the world market.

During 1991, Leo and Schachter & Co. opened the United States' newest, largest, and most modern diamond polishing factory in New York. The factory is fully computerized to track every diamond from rough to finished stone. The computer predicts the cash return

from each piece of rough based on estimates of the rough's color, clarity, yield, and make, estimates are reported to be within 2% of actuals. The factory employs 40 polishers.

Geology-Resources

Gemstones are found in a large variety of igneous, metamorphic, and sedimentary rocks and mineral deposits, usually as a small fraction of the total deposit. The origins are as varied as the deposits. Gemstones form primarily by precipitation from watery solutions, by crystallization from molten rock, and by metamorphic processes. Approximately one-third of gemstones is composed of silicate minerals, about one-fifth of alumina-silicates, and almost one-seventh of oxides. The remaining compositional groups include the sulfides, phosphates, borosilicates, carbonates, and, in the single case of diamond, an element. The composition of selected gem materials is included as one of the items in table 3. (See table 3.)

There are no large resources of major gem materials defined in the United States. Emerald deposits are known in North Carolina, as are ruby and sapphire. Historically, sapphires have been mined in Montana, and significant commercial mining once again is underway. Numerous other domestic deposits of gemstones are known and have been mined for many years. However, no systematic evaluations of the magnitude of these deposits have been made, and no positive statements can be made about their reserve or the size of the resource.

Occasional finds of diamond have been made, but no great diamond pipes or alluvial deposits similar to those of Africa have been reported. Several companies are involved in diamond exploration in the Colorado-Wyoming State line area, in Michigan, Minnesota, Wisconsin, and Arkansas. Diamond-bearing kimberlites have been located and bulk samples have been processed for diamond recovery. Results have not been made public.

World resources of gemstones are nearly all unevaluated. However, world gem diamond reserve is estimated to be

about 300 million carats, including near-gem and cheap-gem qualities. Nearly all of the reserves are in Australia, Africa, and the U.S.S.R. (Siberia). The estimates for diamond reserves are of limited value because data needed for reliable estimates are not available from the producers. Reserve data on other gemstones are even less available than for diamond.

Technology

Synthetic Gems.—Synthetic gemstone production uses many different methods, but they can be grouped into one of three types of processes: melt growth, solution growth, or extremely high-temperature, high-pressure growth.

The year 1902 saw the first production of synthetic ruby using the Verneuil flame-fusion process. Later, sapphire, spinel, rutile, and strontium titanate were grown with this technique. In this process, a single crystal, called a boule, forms in the flame of a simple, downward-impinging oxygen-hydrogen blowtorch. Pure oxides of aluminum (in the cases of ruby, sapphire, and spinel) or titanium (rutile and strontium titanate) are poured into the top of a small furnace and melted. Other oxides are added as needed for process control and to obtain the specific color desired. The melted material solidifies as a boule on a rotating fire-clay peg as the peg is slowly withdrawn.

A boule has a very characteristic shape, with a rounded end; a long, cylindrical body; and a tapering end. It is usually about 13 to 25 millimeters in diameter, 50 to 100 millimeters long, and weighs 75 to 250 carats (a carat is 200 milligrams). Under controlled conditions, boules about 5 millimeters in diameter and more than 890 millimeters long can be produced for the manufacturing of jewel bearings.

Another melt technique is the Bridgman-Stockbargé solidification method, named for an American, P. W. Bridgman, and a German, D. C. Stockbargé, who, aided by three Russians, J. Obreimov, G. Tammann, and L. Shubnikov, discovered and

perfected the process between 1924 and 1936. Currently, the method is used primarily for growing nongem halide, sulfide, and various metallic oxide crystals, one of the metallic oxides being aluminum oxide or sapphire.

The Bridgman-Stockbargé process uses a specially shaped crucible, which is a cylindrical tube open at one end and capped at the other by a small, pointed cone. The crucible is filled with the powdered chemicals necessary to grow a specific crystal and is lowered slowly through a furnace. The small, pointed end of the cone cools first because it is the first part of the crucible that moves from the hottest part of the furnace into cooler regions and it is the first part to emerge from the furnace. As the crucible cools, the molten materials solidify, hopefully in the structure of a single crystal, in the point of the crucible. The crystal then acts as a seed around which the remainder of the molten material solidifies until the entire melt has frozen, filling the container with a single crystal.

This process is simple, and crystals of various sizes can be grown. The crystals are typically about 51 millimeters in diameter and 15 millimeters in length, but large ones exceeding 890 millimeters in diameter and weighing more than 1 metric ton have been grown. The crystals have the same shape as the crucible.

The Czochralski pulled-growth method is used for ruby, sapphire, spinel, yttrium-aluminum-garnet (YAG), gadolinium-gallium-garnet (GGG), and alexandrite. Czochralski developed his method about 1917 while working with crystals of metallic nutrients.

In the Czochralski method, ingredient powders—nutrients—are melted in a platinum, iridium, graphite, or ceramic crucible. A seed crystal is attached to one end of a rotating rod, then the rod is lowered into the crucible until the seed just touches the melt. Then the rod is slowly withdrawn. The crystal grows as the seed pulls materials from the melt, and the material cools and solidifies. Yet, because of surface tension of the melt, the growing crystal stays in contact with the molten material and continues to

grow until the melt is depleted of the desired material.

Typically, the seed is pulled from the melt at a rate of 1 to 100 millimeters per hour. Crystals grown using this method can be very large, more than 51 millimeters in diameter and 1 meter in length, and of very high purity. Each year this method grows millions of carats of crystals for use as gems, laser rods, windows for special scientific or technical applications, and for other industrial applications.

Certain gemstones pose unique problems with regard to attempts to grow them. The problems arise because certain materials are either so reactive that they cannot be melted even in unreactive platinum and iridium crucibles or they melt at much higher temperatures than the crucible materials can endure. Therefore, another melting system must be used, called the skull melting system. Cubic zirconia, because of its high melting point (2,700° C), must be grown using the skull melting method.

The "skull" is a hollow-walled copper cup. Water is circulated through the hollow walls to cool the inside wall of the skull. The cup is filled with powdered ingredients and heated by radio frequency induction until the powders melt. Because the water cools the walls of the skull, the powdered materials next to the walls do not melt, and the molten material is contained within a shell of unmelted material. Therefore, the reactive or high-temperature melt is contained within itself. When the heat source is removed and the system is allowed to cool, crystals form by nucleation and grow until the entire melt solidifies. Crystals grown using this system vary in size, depending on the number of nucleations. In growing cubic zirconia, a single skull yields about 1 kilogram of material per cycle.

Solution techniques for making synthetic gems include flux methods for emerald, ruby, sapphire, spinel, YAG, GGG, and alexandrite. The other solution method is the hydrothermal method, often used for growing beryl (emerald, aquamarine, and morganite) and quartz.

Quartz crystals are grown in a hydrothermal solution in large pressure vessels known as autoclaves. Careful control of temperature and pressure in the different areas of the autoclave result in the feed material, known as lascas, dissolving in the hotter portion. The material redeposits on seed crystals, located in the cooler portion, forming synthetic quartz crystals. The process usually takes 30 to 60 days for the crystals to reach the desired size. The process can also produce rock crystal, amethyst, or citrine.

The same system is used to grow beryl crystals. Beryl seed crystals are suspended in the cooler upper portion of an autoclave. Nutrient materials dissolve in the hotter, lower portion of the autoclave and, because of the temperature and pressure gradients, migrate to the cooler seeds and are deposited. Other techniques involve solid- or liquid-state reactions and phase transformations for jade and lapis lazuli; vapor phase deposition for ruby and sapphire; ceramics for turquoise, lapis lazuli, and coral; and others for opal, glass, and plastics.

The Verneuil, Czochralski, and scull melting processes are the melt techniques most often used for gem materials. The various synthetics and the method of production are shown in table 4. (See table 4.)

Enhancement of Gemstones.—Enhancement of all types of gemstones through chemical and physical means has become much more commonplace and in the past few years has included a wider variety of materials. Irradiation by electromagnetic spectrum (X-rays, gamma rays, etc.) and by energetic particles (neutrons, electrons, alphas, etc.) is being used to enhance or change the color of diamonds, topaz, tourmaline, quartz, beryl, sapphire, zircon, scapolite, and pearls. Blue topaz is normally irradiated, but this does not imply that all of these gem materials are regularly irradiated.¹

Many gemstones can be enhanced by chemical treatment or impregnations. The treatments may alter the bulk of the

gem material or only penetrate the surface. This includes bleaching, oiling, waxing, plastic impregnations, color impregnations, and dyeing. The treatments that alter only the surface of the material include surface coatings of various types, interference filters, foil backings, surface decoration, and inscribing. Chemical treatment is more widespread than just the common dyeing of quartz, treatment of turquoise, and oiling of emeralds. Chemical treatment and impregnations have been used to enhance amber, beryl, chalcedony, coral, diamonds, emerald, ivory, jade, lapis lazuli, opal, pearl, quartz, ruby, sapphire, tiger's eye, and turquoise.²

Since about 1987, fractures, cleavages, and other void-type imperfections that reach the surface in diamonds have been filled using a process developed by Mr. Zvi Yehuda, of Ramat Gan, Israel. This treatment can enhance that apparent clarity of treated faceted diamonds; examples are available that show SI stones enhanced to VS and I1 improved to SI2. Recently, it was announced that Yehuda also had developed a similar treatment for emeralds.

The oldest and most common method of gemstone enhancement is heat treating. Heat treatment of gem materials was used in Greece and Rome well before the Christian Era. Heat treatment can cause color change, structural change, and improve clarity. In the past, heat treatment was common for quartz and gem corundum. Today, materials that are heat treated to enhance their appearance include amber, beryl, diamond, quartz, ruby, sapphire, topaz, tourmaline, zircon, and zoisite.³

Recently, an additional type of treatment for sapphire has appeared—diffusion treatment, a chemical-heat treatment. In this process a thin layer of color is diffused into the surface of the gem. The color may be diffused as little as 0.1 millimeter or as much as 0.4 millimeter into the gem. The treatment is a long process of heat treatment in a bath of chemicals containing the proper proportions of titanium and iron. The American Gem Trade Association (AGTA) adopted a policy for the

disclosure of diffusion treated sapphires. The policy is "If the color of a gemstone is confined to an area near the surface so that the color of the stone would be visibly affected by recutting or repolishing then the following statement must also appear: Although the color induced in the diffusion treated sapphire is permanent, it remains confined to a shallow surface layer." Therefore, recutting or repolishing is not recommended.⁴

Mining.—Gemstone mining operations can range from the most primitive to the most sophisticated. In hard rock, at shallow depths, an operation by one, two, or three persons may be mined by prybar, pick, shovel, and buckets or baskets for carrying material; often drilling and blasting is employed. A larger operation includes drilling, blasting, and minimum timbering. Mechanized hauling and hoisting is done only at the larger mines.

Diamond mining in the kimberlite pipes of Africa and the U.S.S.R. and the lamproite pipes of Australia represent the ultimate in that huge quantities of ore must be mined to extract small quantities of diamond (20 to 30 carats per 100 tons of ore) produced at as low a cost as possible.

Placer mining for gemstones ranges from small-scale, simple procedures to huge, complicated operations. In some areas, digging is by hand, and sorting and recovery is by panning, screening, or sluicing. Diamond miners in the larger placer operations use bucket dredges and heavy-duty excavating equipment, as, for example, in Australia, Brazil, Namibia, the Republic of South Africa, and the U.S.S.R.

Processing.—Most gemstones are broken or crushed where necessary and concentrated by various combinations of hand picking, washing, screening, or jigging. In large-scale operations, mineral beneficiation methods are mechanized and employ the latest technology in each step from primary crushing and screening to the final recovery processes. Diamond recovery,

in particular, makes use of standard gravity methods, grease belts, electrostatic separation, skin-flotation, magnetic separation, separation by X-ray luminescence, and separation by optical sorting.

ANNUAL REVIEW

Production

In 1991, all 50 States produced at least \$1,000 worth of gem materials. Ten States accounted for 95% of the total value of production of natural gemstones. The States, in order of declining value of production, were Tennessee, California, Missouri, South Dakota, Arizona, Montana, Oregon, Texas, Arkansas, and Nevada. Certain States were known best for the production of a single gem material (i.e., Tennessee for freshwater pearls and Arkansas for quartz). Other States produced a variety of gemstones. Arizona produced the greatest variety. Production included agate, amethyst, antlerite, azurite, chrysocolla, fire agate, garnets, jade, malachite, obsidian, onyx, peridot, petrified wood, precious opal, shattuchite, smithsonite, and turquoise. California, Idaho, Montana, and North Carolina also produced a variety of gemstones. Historically, North Carolina is the only State to have produced all four of the major gems: diamond, emerald, ruby, and sapphire.

The average production value of natural gem materials for the past 10 years was \$28.4 million per year, with a high of \$84.4 million in 1991 and a low of \$7.2 million in 1982. The value of production for the past 10 years must be separated into two trends. The first trend was the period between 1981 through 1985, during which time approximately 24 operations reported production. Production averaged \$7.4 million per year and was generally level. In the second trend, 1986 to the present, production averaged \$424 million and was the result of an increase of 1,567% in the number of producers surveyed. The reported value of synthetic and simulant gemstone production was \$17.7 million in 1990. The reported value of

production decreased 17%. The average value of production of these gem materials for the past 6 years was \$16.5 million, with a high of \$20.5 million in 1990 and a low of \$10.3 million in 1986. Fifteen firms, five in California; four in Arizona; and one each in Massachusetts, Michigan, New Jersey, North Carolina, Ohio, and Washington, produce synthetic and simulant gem material. The eight States, in order of declining value of production, were Massachusetts, California, New Jersey, Michigan, Washington, North Carolina, Arizona, and Ohio.

Arizona is well known for the widest variety of gemstones produced by any State. In 1991, they included agate, amethyst, antlerite, azurite, chrysocolla, fire agate, fluorite, garnet, jade, jasper, malachite, obsidian (Apache tears), onyx, peridot, petrified wood, precious opal, shattuchite, smithsonite, and turquoise. Yet, turquoise, peridot, petrified wood, and azurite-malachite accounted for more than 90% of the total value of gem material produced. Production from Arizona of these gemstones was the largest in terms of dollar value in the United States and the world's largest for the first two. Additionally, four manufacturers of synthetic or simulant gem materials were in Arizona and produced about \$100,000 worth of material.

Arkansas is famous for the production of quartz crystals. Yet, Arkansas is second in value of production of freshwater pearls and shells and the only State in the United States that has had any sustained diamond production.

Since 1972 hobbyists have found from 300 to 1,500 diamonds per year at the Crater of Diamonds State Park. From 1906 to the present, it is estimated that production from the deposit is 100,000 to 150,000 carats; this amount of diamond production is insufficient to classify the United States as a diamond-producing country. Still, the potential to become a diamond producer may be there, and efforts were underway to evaluate this potential more fully. The program to evaluate the diamond deposit was halted by legal actions after completing three

exploratory drill holes. Although a Federal appellate court has cleared the way for the program to continue, the program is currently on hold.

Gemstone production from California includes a variety of materials. Tourmaline production from the State is the largest in the Nation, and California has the only producer of benitoite. Additionally, agate, alabaster, beryl, dumortierite, fire agate, freshwater mussel shell and pearls, garnet, gem feldspar, jade, jasper, kunzite, lepidolite, obsidian, quartz, rhodonite, topaz, and turquoise are produced from deposits in the State. Yet, even with this long list of gemstones, most people think of California in terms of its State gem benitoite, its high-quality tourmalines, and its fine orange spessartine garnets.

In May 1989, Pala International reported the discovery of the largest gem tourmaline pocket found in the Himalaya Mine during the past 13 years. The pocket yielded about 500 kilograms of tourmaline; 50% was carving or cabochon grade, less than 1% was faceting grade, and the remainder was specimen grade. The Himalaya continues to produce substantial quantities of fine-quality tourmaline.

As unusual as it may sound, the State also has a freshwater culture pearl farm at Marysville. The farm uses animals imported from Tennessee and other southeastern States. Productions includes pearls, shell, and finished nucleus for cultured pearl implants.

California also has four manufacturers of synthetic or simulant gemstones. The value of production from the State is the second largest for synthetics and simulants.

Colorado is not known as a gemstone-producing State, but it does hold some gemstone honors. For 4 or 5 years prior to 1988, Colorado had the only commercially operated amethyst mine in the United States. It has the only commercially mined deposit of lapis lazuli in the United States and one of the few fee-for-dig topaz deposits currently operating. Additionally, the State was the first to commercially produce turquoise and still has commercially operated

turquoise mines. The State also produced the United State's finest gem-quality rhodochrosite and a quantity of high-quality rhodonite.

Many different locations in the State produce aquamarine, the Colorado State gemstone. The best known locations and the locations with the longest history of continued production (since about 1884) are Mount Antero and White Mountain in Chaffee County. Mount Antero, at 4,349 meters, may be the highest gemstone location in the United States. White Mountain, separated from Antero by a small saddle, is only slightly lower at 4,237 meters.

Star garnet, the Idaho State gemstone, leads the list of gemstones produced in the State. Idaho is one of two places that produce significant amounts of star garnet; India is the other. These almandite garnets are translucent, purplish-red stones that show four- or six-ray stars when cabochon cut or are transparent deep red stones that can be faceted. The primary sources of Idaho star garnet are the placer deposits on the East Fork of Emerald Creek and its tributary gulches in Benewah County. Additionally, the placers of Purdue Creek in Latah County yield star garnets. Currently, garnets that do not cut stars also are commercially mined from areas in Clearwater County. These garnets range from purplish rose-red to a highly prized "special pink." Gem-quality garnets are found at several other locations in Idaho and are mined periodically by hobbyists or professional collectors for the gemstone market.

Opal is the second largest contributor to the total value of gemstone production in Idaho. The varieties produced include precious, yellow, blue, pink, and common. The Spencer opal mine is the largest producer. At the Spencer Mine, precious opal occurs as one or more thin layers within common opal that have partially filled gas cavities within a rhyolite-obsidian flow. About 10% of the material is thick enough to cut into solid gems; the remainder is suitable for making doublets and triplets. The Spencer Mine is also the source of the pink opal, which occurs as either pink

common opal or pink bodied precious opal.

In recent years, an increasing amount of gem material (smokey quartz, aquamarine, topaz, and garnets) was recovered from the Sawtooth batholith. A significant portion of the batholith lays within the Sawtooth National Recreation Area, administered by the Forest Service, U.S. Department of Agriculture. Herein lies a problem. The Forest Service prohibits the collection of gem and mineral specimens from the National Recreation Area under CFR Title 36, 269.9b, which prohibits the removal of "natural features of the land." Additionally, all mining is prohibited in a recreation area. It appears that material is still being collected from the area, but this may stop in the future.

In the U.S. gemstone industry, Maine and tourmaline are almost synonymous. In 1822, Maine's Mount Mica was the site of the first gemstone production in the United States. In 1991, Plumbago Mining Corp. was actively mining the Mount Mica pegmatite for gem material and mineral specimens. Over the years, production from Mount Mica has included hundreds of kilograms of fine-quality gem and mineral specimen tourmaline.

Mount Mica is not the only large producer of high-quality tourmalines. Dunton Mine of Newry Hill is the most prolific gem tourmaline producer in Maine. Since its discovery in 1898, the mine has produced tons of gem- and specimen-grade tourmaline. Other mines and quarries in a three county area produce gem- and mineral specimen-grade tourmalines. These include the Bennett, BB #7, Emmons, Harvard, Tomminen, Waisenen, Black Mountain and Red Hill Quarries, and Nevel Mine in Oxford County. It also includes the Mount Apatite Quarries in Androscoggin County and the Fisher and Porcupine Hill Quarries in Sagadahoc County.

Production from Maine deposits also includes fine-quality beryls—aquamarine, heliodor, and morganite. Pegmatites in Oxford, Androscoggin, and Sagadahoc Counties regularly produce fine-quality blue and blue-green aquamarine, rich

yellow- and gold-colored heliodor, and rose- and peach-colored morganite. In 1989, the largest rose colored morganite on record was found at the Bennett Quarry near Buckfield in Oxford County.

In 1989, Plumbago Mining Corp. opened the most significant commercial amethyst mine in the United States near the town of Sweden in Oxford County. Reported production in the first year of operation was about 2,300 kilograms of gem-quality and specimen-grade amethyst. The gem material has good deep purple color, but is mostly small pieces. An officer of the company did report the cutting of a 12-carat stone from the material and that some material recovered would yield stones as large as 20 carats. The mine did not produce during 1991.

Montana produces many different gemstones, some suited for faceting, while others are better suited for the cutting of cabochons, carvings, or objects-of-art. Montana is noted for the production of sapphires, Montana moss agate, and Dryhead agates. Yet, amethyst, amazonite, azurite, covellite, cuprite, garnet, onyx, opal, petrified wood, rhodochrosite, rhodonite, smokey quartz, sphalerite, and wonderstone (banded rhyolite) are also produced or have been produced from deposit in the State for use as gemstones.

Sapphires have been produced from Montana deposits since 1865. In recent years, Montana sapphire has gained in popularity, and because of the improved popularity, production has increased significantly. Currently, commercial sapphire production is from deposits on the Missouri River in Lewis and Clark County, the Rock Creek area in Granite County, and from the Yogo Gulch area in Judith Basin County. Additionally, there are fee-for-dig sapphire operations on the Missouri River and Rock Creek.

Until 1989, the value of Nevada's gemstone production was essentially dependent upon the production of turquoise and opal, and the production of turquoise was, and still is, declining. In 1989, Nevada reported the first major production of nephrite jade.

The Nevada jade is from a deposit near Tonopah. The material varies in color from different shades of green to black and some is mottled with off-white to tan markings. The reported quality is from fine gem to carving-grade. Mine run jade is available from fist-size pieces to individual boulders that weigh more than 1 ton. The jade is very similar to good to fine Wyoming jade.

Nevada has been a major producer of turquoise since the 1930's, and until the early 1980's, the State was the largest turquoise producer in the United States. Estimates indicate that over the years, 75 to 100 different mines and/or prospects have produced sizable quantities of turquoise. Production varied from a few thousand dollars worth of material at some properties to more than \$1 million at others. Estimates of total production to date are between \$40 to \$50 million.

Precious opal production from deposits in the Virgin Valley area began in about 1906. The opal from Virgin Valley is comparable to any in the world for its vivid play of color and is unsurpassed in terms of the size of material available. The material varies in color from deep pure black to brown to yellowish-white to white to colorless. The play of color includes all the colors common to precious opal—red, blue, green, yellow, orange, and so on. The opal is found primarily as replacement of wood, or sometimes, the replacement of cones of conifer trees. The use of the opal is greatly restricted because of a severe problem with crazing. Currently, two mines in Virgin Valley are open to individuals on a fee-for-dig basis during the summer months. The operators of these mines also mine the deposits for their own inventories.

North Carolina is the only State in the United States where all four major gem materials, diamond, ruby, sapphire and emerald, have been found. During 1988 was the last time all four major gemstones were found in the same year. The diamond was found in a gold placer mine, rubies and sapphires were recovered from the Cowee Valley, and emeralds were found near Hiddenite and Little Switzerland.

Production of ruby and sapphire from deposits along the Cowee Valley in Macon County began in 1895 when the American Prospecting and Mining Co. systematically mined and washed the gravels of Cowee Creek. Today ruby, sapphire, and fee-for-dig operations are in the Cowee Valley. Many people pay to dig or purchase buckets of gravel to wash to recover gem corundum, garnets, and other gemstones.

Every year there is publicity concerning the discovery of large and valuable rubies and sapphires at one or more of the mines in Cowee Valley. No doubt large corundum crystals and pieces of corundum are found each year. Similarly, valuable rubies and sapphires may be found, but the number of large and valuable gems and the values of these gems often are overstated. During the period when commercial mines operated in the area, gemstones were found that would cut fine-quality 3- to 4-carat stones. Today, the amount of quality gem material has greatly declined. Most of the rubies found are not of top color or clarity and on average are suitable for cutting stones of 1 carat or less. The sapphires tend to be larger than the rubies and high-quality sapphires are more abundant than high-quality rubies.

In 1875, emeralds were discovered near what is now Hiddenite, with the first attempts at commercial mining of emeralds in the Hiddenite area in 1881. Other attempts were made in the 1920's, the 1950's, the 1970's, and the latest attempt ended in 1990. At different times the emerald deposits in the Hiddenite area have produced large emerald crystals, and some significant stones have been cut from Hiddenite material. Yet, to date, it has not been possible to maintain an economically viable mine operation on any of the deposits. This includes the last attempt that would have mass mined the deposit and used a beryllometer to sort the emerald from the waste rock. The beryllometer worked well, but the amount of emerald present did not support the project.

Historically, Oregon has been known for the production of various picture and scenic jaspers, agates, thunderegg,

petrified wood, and to a certain degree, gem labradorite. Oregon's State rock, the "thunderegg," may be the best known gem material from Oregon. Graveyard Point, Priday, and Polka Dot are names that are uniquely associated with beautiful Oregon agates. The same is true for the relationships between the names Biggs, Deschutes, and Sucker Creek and picture or scenic jasper. Yet, gem labradorite (sunstone) is currently the largest single contributor to the value of annual gemstone production in Oregon. At least seven firms or individuals currently are producing sunstone from three different geographic areas.

The other gemstone to contribute significantly to the value of production from Oregon is opal. During 1988, the first significant commercial mining and marketing of a variety of very fine quality opals from Opal Butte began. The varieties include hyalite, rainbow, contra luz, hydrophane, crystal, fire, blue, and dendritic. Exquisite stones as large as 315 carats have been cut from contra luz rough from this deposit.

Tennessee has the largest U.S. production of freshwater mussel shells and pearls of the 11 producing States. The fishing and marketing of freshwater mussel shells and pearls are not new in the United States or in Tennessee. There has been an established U.S. freshwater mussel fishing industry since the mid-1850's. The mussels are from the family Unioidea, of which about 20 different species are commercially harvested. During 1991 the value of U.S. mussel shell exports was more than \$63 million.

To date, freshwater pearls from the United States have been a byproduct of the shell industry. Currently, the primary use of the shells is to make the bead nucleus used by the Japanese cultured pearl industry. Additionally, the shells are used in making cameos and as mother-of-pearl. With the coming of the freshwater cultured pearl farms in Tennessee and the increasing popularity of freshwater pearl jewelry with the U.S. consumer, this may change. In 1963, the first experimental U.S. freshwater cultured pearl farm was established. Since the technology for culturing

freshwater pearls was proven in the late 1970's, six freshwater pearl farms have been established. These farms are the beginning of the U.S. freshwater cultured pearl industry, and the cultured pearl is the heart and future of the U.S. pearl industry.

The gemstone that Utah is best known for, topaz, is not well suited for use as a gem, but it does make a fine mineral specimen. Topaz crystals have been collected from certain rhyolite flows in the Thomas Mountains for more than 100 years. Similar crystals also are found in select rhyolites in the Wah Wah Mountains. The crystals from the Thomas Mountains are predominately small, 10 to 20 millimeters long and 4 to 6 millimeters across, and crystals from the Wah Wah Mountains are even smaller. Occasionally, large gem-quality crystals are found. The color of the topaz varies from colorless to light yellow, sherry brown, rose or light pink. Unfortunately, the light yellow to sherry brown color fades to colorless if exposed to sunlight or heat and rose- or light pink-colored crystals are rare. Because of the size of the crystals and problem with color fading, the material yields only small to very small colorless stones.

Another Utah gemstone with nearly a 100-year production history is variscite, first produced in about 1893 near Fairfield. The latest recorded commercial production was from near Lucin during the summer of 1991. Variscite is found as fracture fillings or as nodules. The nodules may be solid, almost geode in nature, or fractured solid nodules that have undergone alteration. The color of the variscite varies from deposit to deposit and from location to location within the same deposit. It is a shade of light to dark yellow-green, but can be a dark, nearly jade green and so pale as to appear almost white. It also can have black and brown spiderwebbing.

Another material from Utah is snowflake obsidian. Snowflake obsidian (also known as flower obsidian) earns its name from the bluish-white or grayish-white patterns of cristobalite included into the normally black obsidian. During

1991, two different firms produced this material commercially.

Topaz, variscite, and obsidian from Utah are well known and are nice materials. But, in the author's opinion, the red beryl from the Wah Wah Mountains is the most remarkable and desirable of Utah's gemstones. Bixbite, the variety name for red beryl (called red emerald by some) is found in rhyolites at several locations in the Thomas and Wah Wah Ranges. The beryl varies in color from a pink to bright red, with the bright red being what could be called strong raspberry-red. The material from most of the locations is not as spectacular, either in crystal size or color, as the crystals from the Violet claims in the Wah Wah's.

The Violet claims in the Wah Wah's are the only known location for commercial production of red beryl. In recent years, the claims have furnished a small but steady supply of materials for both mineral specimens and a few fine-quality gems. The crystals average about 10 millimeters in length, and most are flawed. Because of the size of the crystals and flaws, finished stones only average about 0.40 carat with few more than 1 carat. The largest finished stone to date is only 4.46 carats. The material is expensive, but justifiably so, because of its beauty and rarity.

Certain other States produce a single gem material of note, they are: Alaska with its two jade mines; Florida's agatized coral; Hawaii's black coral; Minnesota's thomsonite; New York's herkimer quartz; Ohio's flint; and South Dakota's rose quartz.

The value of 1991 production by individual gemstone can be reported for those materials that have three or more producers and if one of the three does not account for more than 75% of the total or two of the producers account for 95% or more of the production. (See table 5.)

Consumption and Uses

Consumption of domestic gemstones was in the commercial and amateur manufacture of jewelry, for exhibit in gem and mineral collections, and for

decorative purposes in statuettes, vases, other art objects, and certain industrial applications.

Frequently, tourmaline is used as a standard for calibrating piezoelectric manometers and testing devices. It is also a control substance in boron experiments because it is itself an inert boron-containing compound. Tourmaline is the standard used in tests to check possible effects of water-soluble boron in fertilizers.

Many scientific and industrial instruments use tourmaline. One such use is tourmaline tongs, a simple laboratory instrument that shows the polarization of light. Because tourmaline is both pyroelectric and piezoelectric, meaning it generates electricity when heated or compressed, it is a component of instruments for measuring high pressures and fluid compressibility. Thermal dosimeters, which were early instruments that measured the intensity of radium emanations, depended upon tourmaline's pyroelectric properties.

Once the mark of a top-rated watch or timepiece was that it was Swissmade and had 18 or 21 ruby or sapphire jewel bearings. Originally, these jewel bearings were made from natural ruby and sapphire. Later, the availability of inexpensive synthetic gemstones allowed the natural materials to be replaced in the manufacture of jewel bearings.

Why are ruby and sapphire used as bearings? Because ruby and sapphire, color variations of the mineral corundum, are second only to diamond in hardness; they have no cleavage (cleavage being the tendency for a crystallized mineral to break in certain definite directions, indicates a minimum value of cohesion in the direction easy fracture) and thus they are very durable; they have a very low coefficient of friction when highly polished; they are chemically inert; and they can be cut and polished without great difficulty.

Watches were not the only instruments in which sapphire and ruby bearings were used. Most precision gauges in aircraft and boats depend upon jewel bearings, as do many gauges, meters, and other instruments in manufacturing and

chemical plants. The military is still highly dependent on jewel bearings for many of its high-tech weapons systems. Recently, another use for one type of jewel bearing appeared—as connectors for optical fibers.

In recent years, technological advances allowed the growth of large, high-quality synthetic ruby crystals, called laser ruby, for the manufacture of laser rods. Several other synthetic gemstones also are being produced for lasers, including chromium-doped chrysoberyl (dope being a element added to the crystal growing nutrients to achieve a particular color), synthetic alexandrite, and varieties of doped yttrium-aluminum-garnet (YAG).

Lasers require high-purity, optically perfect crystals. The crystal must be large enough so that a laser rod can be cut from the raw crystal, and the mineral or material must have the correct physical properties to allow light amplification without the necessity of excessive energy. Synthetic ruby, sapphire, and YAG have all these characteristics.

Over the years, both natural and synthetic corundum have been ground and graded as an abrasive. Corundum was the major compound used in the polishing of eyeglass lenses. While industrial diamond has replaced much of the corundum used in the lens-polishing industry, some polishers still use corundum for specialized lenses.

Other gem materials have enjoyed limited uses in nongem applications. The abrasive and ceramic industries use topaz as a raw material because of its hardness and chemical features. Once, lenses for eyeglasses were made from gem-quality beryl—if the morganite variety of beryl were used, one would truly be looking at the world through rose-colored glasses. Mortar and pestle sets, knife edges for balances, textile rollers, and spatulas are some nongem uses of agate.

Some industrial applications requiring clean homogeneous stones used low-quality gem diamond. The quantity of natural and synthetic industrial-grade diamonds used in the United States each year is 12 to 15 times greater than the amount of diamonds consumed by the jewelry industry.

The 1991 estimated value of U.S. apparent consumption was \$3,059 million, down about 18% for 1989's record high. The average annual estimated consumption for the past 10 years was \$2,871 million, with a high of \$3,711 in 1989 and a low of \$1,642 in 1982. The trend for estimated consumption for the past 10 years was one of continued growth, with about 68% total increase.

In 1991, the value of U.S. estimated apparent consumption of diamonds was essentially unchanged from that of 1990 at \$2.6 billion. The average annual value of apparent consumption of diamonds for the past 10 years was \$2,419 million, with a high of \$3,115 million in 1989 and a low of \$1,279 million in 1982. The trend for the value of apparent consumption for the past 10 years was one of significant increase. The value of apparent consumption of diamonds increased 100% over the period.

The 1990 estimated apparent consumption of colored stones, led by emerald, ruby, and sapphire, was valued at \$397.1 million, a decrease of 3%. The annual average value of consumption of colored stones for the past 9 years was \$325.0 million, with a high of \$406.9 million in 1989 and a low of \$252.4 million in 1982. The trend for apparent consumption of colored stones for the past 9 years was one of fluctuating increases and decreases, but the general trend was one of increased consumption.

The estimated apparent consumption of pearls—natural, cultured, and imitations—was \$19.5 million, an increase of about 18% from the 10-year low in 1990. The average annual consumption for the past 10 years was \$163.0 million, with a high of \$244.7 million in 1984 and a low of \$16.5 million in 1990.

Estimated apparent consumption of synthetic and imitation gemstones decreased about 78% to \$20.9 million. Average apparent consumption of these materials for the past 10 years was \$51.8 million per year, with a high of \$109.1 million in 1987 and a low of \$13.9 million in 1982. The trend for apparent

consumption for the past 10 years was one of generally strong growth except for the significant decrease in 1989 and 1991. Annual apparent consumption at the end of the period was 50% greater than at the beginning of the period. The U.S. Department of Commerce reported that jewelry store retail sales were \$13.8 billion, a 3.6% decrease compared with those of 1990.

Prices

Demand, beauty, durability, rarity, freedom from defects, and perfection of cutting determine the value of a gem. In establishing the price of gem diamond, the CSO's control over output and prices also is a major factor.

The average U.S. wholesale asking price of the top 25 grades (D through H color and IF through VS2 clarity) of a 1-carat diamond fluctuated between \$7,200 and \$7,300, and was \$7,300 at yearend. The average value per carat of all grades, sizes, and types of gem-quality diamond imports was \$517, a slight decrease compared with that of 1990. The average value of diamond imports for the past 10 years was \$405 per carat, with a high of \$525 in 1990 and a low of \$353 in 1984. The trend for the average annual value of diamonds imported for the past 10 years was one of general decline from the 10-year high in 1980 to stable prices in 1986, 1987, and 1988, followed by the 1989 and 1990 increases.

The average yearend wholesale purchase price of a fine-quality 1-carat ruby, paid by retail jewelers on a per stone or memo basis, was \$4,200, an increase of 20% from that of 1989. The average value of ruby imports decreased 39% to \$29.80 per carat. The average annual value of ruby imports for the past 10 years was \$37.12 per carat, with a high of \$48.71 in 1990 and a low of \$16.42 in 1984. The trend for the value of ruby imports for the past 10 years was one of rapid decline, 52% for the period from 1982 to 1984. This was followed by a steady, moderate increase until the 1991 decrease.

The average yearend wholesale purchase price of a fine-quality 1-carat

sapphire, paid by retail jewelers on a per stone or memo basis, was \$1,600, a 14% increase from that of 1989. The average value of sapphire imports increased 8% to \$23.31 per carat. The average annual value of sapphire imports for the past 10 years was \$23.23 per carat, with a high of \$27.97 in 1987 and a low of \$18.50 in 1984. The trend for the value of sapphire imports for the past 10 years was one of fluctuating increases and decreases. The 10-year period ended with the 1991 value 5% below the 1982 value.

The average yearend wholesale purchase price of a fine-quality 1-carat emerald, paid by retail jewelers on a per stone or memo basis, was \$2,750, the same as for 1989. The average value of emerald imports decreased 4% to \$42.01 per carat. The average annual value of emerald imports for the past 10 years was \$55.65 per carat, with a high of \$78.79 in 1988 and a low of \$35.06 in 1984. The trend for the value of emerald imports for the past 10 years was one of fluctuating increases and decreases from 1982 through 1984. A steady moderate growth followed until the 3 years of decline in 1989, 1990, and 1991. The average value in 1990 being about 76% of the 1981 value. (See tables 6 and 7.)

Foreign Trade

The value of exported exports plus reexports increased 9% to \$1,712 million, a record high. The quantity of cut diamonds exported and reexported increased slightly to 1,008,154 carats, and the value of diamond exported and reexported decreased slightly to \$1,351.2 million. The average annual quantity of cut diamonds exported and reexported for the past 10 years was 577,581 carats, with a high of 1,008,154 in 1991 and a low of 184,871 in 1982. The trend for the quantity of cut diamonds exported and reexported for the past 10 years was one of significant growth, 445%, from 1982 to 1991. The average annual value of cut diamonds exported and reexported for the past 10 years was \$734.6 million, with a high of \$1,398.8 in 1990 and a low of \$292.8 million in 1982. The trend for

the value for the past 10 years was one of fluctuating increase and decline over 3 years, followed by 6 years of growth, 32%, and then 1 year of slight decline. The period ended with value of exports and reexports 361% greater than at the start of the period.

The value of other precious stones, cut but unset and other than diamonds and pearls, exported and reexported increased to \$71.9 million. The 10-year trend for value of exports plus reexports of these types of gemstones was one of fluctuating increases and decreases, but one resulting in a significant overall total increase for the period. The value of exports and reexports of other precious stones not cut or set was \$113.6 million. An additional \$22.1 million worth of other gemstones was exported or reexported during 1991.

The value of synthetic gemstone exports plus reexports was \$21.9 million. The 10-year trend for the value of exports plus reexports was one of extreme decline during the period between 1982 to 1988, followed by significant growth, 608%, during 1989-90, and then a significant decline in 1991.

The value of natural, cultured, and imitation pearls, not set or strung, exports and reexports of pearls increased significantly to more than \$4.2 million.

The value of gems and gemstones imported increased slightly to \$4,640.6 million compared with those of 1990, but still below the 1989 record high of \$5,115 million. The value of imported gem diamonds accounted for about 86% of the total. The average annual value of gems and gemstones imports for the past 10 years was \$4,027 million, with a high of \$5,115 million in 1989 and a low of \$2,384 million in 1982.

The value of imported gem diamonds increased slightly to \$3992.0 million compared with that of 1990, but below the 1989 record high of \$4,358 million. The 10-year trend for the value of diamond imports was one of generally steady continuous growth until the decline in 1990 and the small growth in 1991 that resulted in current value still being less than that of 1988. Even with the downward adjustment, total increase for the period was 108%. During the period

the value of imported uncut diamonds increased 91%, while the value of cut stones imported increased 111%.

The imports of cut diamonds increased 6% in quantity and 2% in value to 6.7 million carats and \$3,464.6 million, respectively. The average annual quantity of cut diamonds imported was 6.9 million carats, with a high of 8.9 million in 1989 and a low of 1.6 million carats in 1982. The trend for the quantity of cut diamond imports for the past 10 years was one of continued increases until the 1990 decline; the period still ended with imports 79% greater than at the beginning of the period. The average annual value of cut diamond imports was \$2,929.2 million, with a high of \$3,805.5 in 1989 and a low of \$1,641.0 million in 1982. The trend for the value of cut diamond imports for the past 10 years was of strong growth and increases. The value at the end of the period was 111% greater than at the beginning.

The value of imports of other gem and gemstones, led by emerald, ruby, and sapphire, was \$531.1 million, a decrease of about 5% compared with that of 1990. Emerald imports increased slightly to \$165.5 million. The average annual value of emerald imports for the past 10 years was \$155.3 million, with a high of \$207.5 million in 1989 and a low of \$120.8 million in 1982. The 10-year trend for the value of emerald imports was one of fluctuating increases and decreases resulting in a 37% increase for the period.

The value of ruby imports decreased 28% to \$70.9 million from 1990's record-high value for the past 10 years of \$98.4 million. The average annual value of imports for the past 10 years was \$74.9 million, with a high of \$98.4 in 1990 and a low of \$58.7 in 1987. The 10-year trend for import values was one of extreme fluctuations. The period ended with values having increased 21% from the 10-year low for the period.

The value of sapphire imports was \$81.6, essentially unchanged from that of 1990. The average annual value of sapphire imports for the past 10 years was \$81.7 million, with a high of \$100.0

million in 1989 and a low of \$63.3 million in 1982. The 10-year trend for the value of imports was one of extremely fluctuating increases and decreases. The period ended with the value 29% greater than that at the beginning of the period.

The value of imported gem materials other than diamond, emerald, ruby, and sapphire increased slightly to \$213.1 million. The average annual value of imports was \$332.5 million, with a high of \$429.5 in 1988 and a low of \$210.3 in 1990. The 10-year trend for the value of imports was one of fluctuating increases and decreases resulting in the period ending essentially at the same level that the period started. (See tables 8, 9, 10, 11, and 12.)

World Review

Diamond sales by De Beers Centenary AG was \$3.93 billion in 1991, a decrease of 6% compared with 1990 sales of \$4.17 billion. Sales during the second half of 1991 were only \$1.84 billion, 11% less than the \$2.08 billion sales for the second half of 1990. A De Beers official stated that the reduction in sales was the result of the Persian Gulf war and the economic turndown in the United States. De Beers controls about 80% of the rough, uncut diamonds sold in the world. Sales of colored stones remained strong.

In May, De Beers unveiled the 273-carat Centenary diamond, reportedly the largest top-colored, flawless diamond outside of the British Crown Jewels. The Centenary was cut from a 599-carat piece of rough recovered at the Premier Mine in the Republic of South Africa in 1986. Three years were spent in preparing, cutting, and polishing the modified heart-shaped stone. The Centenary is insured for more than \$100 million.

Natural diamond production occurs in Africa, Asia, Australia, and South America. The principal producing localities are as follows: in Africa—Angola, Botswana, Namibia, the Republic of South Africa, and Zaire; in Asia—U.S.S.R. (northeastern Siberia and in the Yakut A.S.S.R.); in Australia;

and in South America—Venezuela and Brazil. (See table 13.)

Foreign countries in which major gemstone deposits (other than diamond) occur are Afghanistan (beryl, kunzite, ruby, tourmaline); Australia (beryl, opal, sapphire); Brazil (agate, amethyst, beryl, kunzite, ruby, sapphire, tourmaline, topaz); Burma (beryl, jade, ruby, sapphire, topaz); Colombia (beryl, sapphire); Kenya (beryl, garnet, sapphire); Madagascar (beryl, rose quartz, sapphire, tourmaline); Mexico (agate, opal, topaz); Sri Lanka (beryl, ruby, sapphire, topaz); Tanzania (tanzanite, garnet, ruby, sapphire, tourmaline); and Zambia (amethyst, beryl).

Angola.—The Government of Angola's diamonds company, Endiama, entered into a prospecting agreement with a Portuguese-Zairian consortium. The consortium is Sociedade Portuguesa de Investimentos and SAICAN; both firms are privately held. It is reported that the Zairian firm may have links with President Mobutu Sese Seko of Zaire. The prospecting rights are along the Cuango River near the Angola-Zaire border, the same area included in the April diamond sales agreement between Angola and De Beers Centenary.⁵

Australia.—Stirling Resources NL has entered into a joint venture with Sabminco NL on Stirling's Boab Creek exploration license in West Kimberleys of Western Australia. Stirling has identified what is interpreted to be a potential kimberlite pipe and buried alluvial channel. The license is adjacent to Sabminco's Diamond Mountain project area where Sabminco has recovered gem-quality diamonds from drill holes in a buried alluvial channel.

Brazil.—The Director of the Brazilian Gem and Precious Metal Institute announced that he expected that exports of cut gems and uncut gemstones would be about \$200 million for 1991. This would be an increase of 18% compared with 1990's \$170 million worth of

exports. He is hopeful that exports will increase to as much as \$500 million within 2 years. One reason for the increase in exports is that the domestic market is weak; in 1980 domestic purchases of gemstones was \$800 million, in 1990 they were \$360 million, and only \$300 million in 1991.

Canada.—Uranerz Exploration, operator of its joint venture with Cameco, announced the recovery of additional diamonds from drill samples from the Fort a la Corne property. The latest stones recovered averaged 0.04 carat with the largest at 0.6 carat. Some on the stones recovered were of gem quality.

Uranerz's exploration program has identified 70 potential kimberlite pipes in a corridor that is 50 kilometers by 20 kilometers from Price Albert to Nipawin in Saskatchewan. The first 15 sites tested proved to be kimberlites, and to date a total of 160 diamonds have been recovered from drill cores. Uranerz is playing down the exploration results, but experts are speculating on the possibility of a diamond mine in Saskatchewan by the end of the decade. Normally, geologists search for indicator minerals, minerals that form under the same conditions as diamonds, but at the Fort a la Corne property they found the actual diamonds in the drill samples.

Dia Met Minerals Ltd. announced the results of the analysis of one drill hole on the Dia Met and BHP-Utah Mines Point Lake prospect, a 800-square-kilometer joint venture in the Northwest Territories. Analysis of a 59-kilogram sample of core taken from between 140 and 180 meters yielded 81 diamonds each less than 2 millimeters in diameter. The drill hole was in a kimberlite pipe that is estimated to have a surface area of between 162,000 and 324,000 square meters and to have a depth of 1 kilometer. The Point Lake prospect is about 480 kilometers north of Yellowknife, the capital of Northwest Territories. The announcement has set off a rush to stake claims around the Point Lake prospect.

China.—A 60.5-carat diamond was unearthed from the Wafangdian Mine in

Dalian city in northeast Liaoning Province. Since the Wafangdian Mine went into production in 1990 many diamonds more than 10 carats have been found.⁶

Argyle Diamonds has opened a diamond cutting and polishing factory in China. The factory is a joint project between the Australian International Development Assistance Bureau and the China Pearl, Diamond, Gem, and Jewelry Import and Export Corp.

The factory, about 30 kilometers from the center of Beijing, is one of the most modern and best equipped training factories in the world. It is planned for the factory to train about 900 cutters by the end of 1992. The factory began training with five Australian trained Chinese cutters and nine skilled international trainers recruited by Argyle.⁷

Cook Islands.—In June, about two-thirds of the 39,000 black pearls offered in the first full auction by Cook Islands Pearls Ltd. was sold. A total of 54 lots, with a reserve price of \$2.7 million, was expected to bring more than \$4.5 million. The highest successful bid for a single lot was \$114,000 by Kikuchi Pearl Co. Ltd. of Japan.⁸

Ghana.—The Government of Ghana, Lazare Kaplan of the United States, and Inco Ltd. of Canada have entered into an agreement to mine and market Ghanaian diamonds. This is the first privatization of the diamond industry under the current Government. The agreement was 2 years in the making.

The agreement calls for a two-phased mining plan, the first of which will take 7 to 11 years to complete. The mine will be brought to a production level of about 0.5 million carats per year. The second phase will bring the mine to a production level of about 1 million carats per year. Currently, the mine production is between 0.1 and 0.2 million carats per year.

Murtob Mining Co. Ltd. of Akwatia purchased a diamond concentrating plant from Somerville Engineering Associates

of England. The plant is trommel and jig-grease tables style.

Guinea.—Bridge Oil Inc.'s Aredor Mine recovered another 100-plus carat stone. Since 1986 the Aredor Mine has produced more than five stones more than 100 carats. The latest stone was 192.9 carats and estimated to be worth more than \$2.0 million. The other large stones were; 100 carats sold in 1986 for \$1.56 million, 143 carats sold in 1987 for \$3.65 million, 181.77 carats sold in 1988 for \$8.62 million, and a 255.6 carat sold for more than \$10 million in 1989. The largest stone on record for the Aredor Mine was a nongem-quality 460-carat stone.⁹

India.—Total rough diamond imports for 1991 increased 57% in volume to 59,990,000 carats compared with those of 1990, while the value decreased 0.5% to \$1,990 million. The net polished diamond exports for 1991 totaled 8,817,000 carats valued at \$2,564 million, an increase of 0.2% and a decrease of 5%, respectively, compared with those of the previous year. This reflected the demand for cheaper goods for most of the year.

Ashton Mining, an Australian company, negotiated an agreement with the Indian National Mineral Development Corp. to assist in the modernization of the Panna Mine. The mine produced about 20,000 carats of diamonds in 1991, and the modernization is intended to increase production by increasing the amount of ore processed.

Indonesia.—Indonesian Diamond Corp. was delayed in the construction of its diamond plant in South East Kalimantan. The plant was ready for production in December 1991. The pilot plant, capable of running about 30 cubic meters per hour, processed material from the mine until the commercial plant was completed. The delay and cost overruns resulted in the plant costing about \$1.1 million more than the original estimate of \$2 million. The first diamonds from the commercial operation, 2,200 carats, were

sold for an average price of \$191 per carat. It is planned to operate both plants in the coming year to process about 54,000 cubic meters of ore per month and recover about 5,400 carats of diamonds each month.

Israel.—Israel has established a joint venture involving the U.S.S.R. and Panama to polish and market emeralds from the Ural area of the U.S.S.R. The joint venture will operate under the name Emural and have exclusive right on the U.S.S.R. emeralds for the next 50 years.

Two Israeli companies, Hargem and Izumrud, will supply the company with training as well as the polishing equipment and technology. Two factories were opened in the U.S.S.R. with about 200 workers and 4 Israeli experts. The joint venture is expected to eventually supply about 20% of the world emeralds.

The 1991 exports of polished diamonds from Israel were valued at \$2,472 million, an 11% decrease compared with those of 1990. During the year, 630 diamond cutting factories employed more than 9,500 workers.

Namibia.—Consolidated Diamond Mines (CDM) began production at the open pit Elizabeth Bay Mine in June. It is planned that the mine will produce about 4 million tons of ore per year that will result in the recovery of about 250,000 carats of diamonds. The production from the Elizabeth Bay Mine will increase CDM's annual production to about 1 million carats per year. During the expected 10-year life of the mine, the mine should produce about 2.5 million carats of diamonds.

Monarch Minerals and Mining, Inc., a U.S. firm, announced production began at its new diamond mine in southeastern Namibia in July. The mine is located on Monarch's 50-square-kilometer mining concession at the mouth of the Fish River.

Tahiti.—Sales of black pearls at the 14th International Pearls Sale in Papeete, Tahiti, were 48,771 pearls for \$4.97 million. These sales represented an

increase of 19% in the number of pearls sold, but the total value of sales decreased 17% and the average price per pearl decreased 30% compared with those of 1990. The pearls ranged in size from 8.5 to 18 millimeters in diameter and were of much better quality than in recent years. There were 40 overseas buyers at the auction representing companies from 6 different countries.

Tanzania.—Late in the year the Government of Tanzania urgently invited tenders from competent companies for mineral rights at the Merelani tanzanite area, Arusha region. The tender areas are nine 200-meter by 300-meter blocks. The applicants must be experienced gemstone miners, processors, and marketers. Additionally, they must indicate the prospecting methods they intend to use, the availability of equipment, the method of drilling, a detailed work program, security arrangement for the mine, and the financial commitment to the program. The successful applicants will be required to post a \$25,000 bond.

U.S.S.R.—Reports on Radio Moscow indicate the discovery of a major diamond field in Buryatskaya on the Soviet side of the Mongolian border. It is reported that more than 10 diamond-bearing sites in the eastern part of the Sayany Mountains were found. The discovery comes after 50 years of small-scale prospecting in the region, during which small quantities of diamonds were found.

The world's biggest new source of diamonds in this century may be the five kimberlite diamond pipes near the village of Pomorie at Lamonsov in the North Russian oblast of Archangelsk. Development plans for the pipes are for two shafts to a depth of about 1,000 meters, one on each side of the pipe. The cost to develop the five pipes, including the infrastructure and power station, is estimated to be \$4 billion. Funds of the project will have to come from foreign sources or joint ventures.

Tokyo Maruichi Shoji Co. (Maruichi) of Japan entered into a joint venture with the Yakut Autonomous Soviet Socialist

Republic for Maruichi to produce an unspecified amount of diamonds from the Republic for export to Japan. According to the agreement, approximately 10% of the diamonds will be cut and polished prior to export. This appears to be one step in the Yakut authorities taking control of the Republic's diamond production from the central U.S.S.R. Government.

Zimbabwe.—Auridium Consolidated NL of Australia has acquired the exploration license for the Ranch River diamond project that was forfeited by De Beers early in 1991. Kimberlitic Searches Ltd., a De Beers subsidiary, evaluated the project in the early 1980's and found the diamond project was uneconomical at that time. Auridium and its partner, Cornerstone Investments, Ltd., believe that given the current diamond market the project may be economical during the 1990's. Evaluations will be undertaken to determine if the deposit is economical at this time.

Delta Gold NL of Australia has applied for exploration rights in eight diamond-bearing areas totaling about 4,600 square kilometers. The company already has completed a great deal of fieldwork in the selected areas.

Current Research

An oval jade cabochon in a ring offered to Sotheby's Hong Kong Ltd. from its 1990 jadeite jewelry auction was found to have been treated with a new procedure to improve its appearance. Testing by the Hong Kong Gems Laboratory discovered a coating that is a highly adhesive, colorless organic resin mixed with a chemical compound that makes it resistant to high temperatures. The Gemological Association of All Japan found an oval jade cabochon that had exceptionally good color, luster, and transparency that was poor-quality, white jadeite treated with a green resinous coating. The coatings can be identified by immersing the piece in methylene iodide and shining a bright light on the stone to display the thin transparent layer of the coating.¹⁰

OUTLOOK

World demand for gem diamond can be expected to rise because of increasing effective personal incomes and the populations of the United States and other industrialized countries. Also, demand will increase because of highly effective promotional efforts. These promotions are changing social customs in many eastern countries, particularly the use of diamond engagement rings. The changes are resulting in significant growth in the diamond market. Demand for other precious gems will continue to grow as diamonds become more expensive and the popularity and acceptance of colored gemstones increase. Demand for synthetic and simulant gemstones for both personal and industrial consumption is expected to increase. The diversity of sizes, types, uses, and values of gems and gemstones precludes any meaningful forecasting of future demand.

¹Nassau, K. *Gemstone Enhancement*. Butterworth, 1984, pp. 46-60.

²CRA Gazette. July 1991, pp. 61-78.

³Pages 25-44 of work cited in footnote 2.

⁴Rapaport Diamond Report. Colored Stones Section. V. 15, No 9, Mar. 6, 1992, p. 26.

⁵Diamond Registry Bulletin. V. 23, No. 7, July 21, 1991, p. 3.

⁶Mining Journal. V. 316, No. 8128, June 28, 1991, p. 491.

⁷Page 6 of work cited in footnote 2.

⁸Business. Pacific Islands Monthly, v. 61, No. 7, July 1991, p. 48.

⁹Mining Journal. V. 317, No. 8132, July 26, 1991, p. 67.

¹⁰Jewellery News Asia. No. 75, Nov. 1990, p. 90.

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TABLE 1
DE BEERS' CSO ROUGH DIAMOND PRICE INCREASES, BY
PERCENTAGE

Sept. 1949	25.0	Nov. 1967	16.0	Aug. 1973	10.2	Sept. 1982	2.5
Mar. 1951	15.0	Sept. 1968	2.5	Dec. 1974	1.5	Apr. 1983	3.5
Sept. 1952	2.5	July 1969	4.0	Jan. 1976	3.0	Aug. 1986	7.5
Jan. 1954	2.0	Nov. 1971	5.0	Sept. 1976	5.8	Nov. 1986	7.0
Jan. 1957	5.7	Jan. 1972	5.4	Mar. 1977	15.0	Sept. 1987	10.0
May 1960	2.5	Sept. 1972	6.0	Dec. 1977	17.0	Apr. 1988	13.5
Mar. 1963	5.0	Feb. 1973	11.0	Aug. 1978	30.0	Mar. 1989	15.5
Feb. 1964	7.5	Mar. 1973	7.0	Sept. 1979	13.0	Mar. 1990	5.5
Aug. 1966	7.5	May 1973	10.0	Feb. 1980	12.0		

TABLE 2
DE BEERS' CSO ROUGH
DIAMOND SALES AND STOCKS

(Billions of dollars)

Year	Sales	Stocks
1982	1.30	1.71
1983	1.50	1.85
1984	1.61	1.95
1985	1.80	1.90
1986	2.56	1.85
1987	3.07	2.30
1988	4.17	2.00
1989	4.09	2.47
1990	4.17	2.68
1991	3.93	3.03

TABLE 3
GUIDE TO SELECTED GEMSTONES AND GEM MATERIALS USED IN JEWELRY

Name	Composition	Color	Practical size ¹	Cost ²	Mohs	Specific gravity	Refraction	Refractive index	May be confused with-	Recognition characters
Amber	Hydrocarbon	Yellow, red, green, blue	Any	Low to medium	2.0-2.5	1.0-1.1	Single	1.54	Synthetic or pressed, plastics	Fossil resin, soft.
Beryl:										
Aquamarine	Beryllium aluminum silicate	Blue-green to light blue	Any	Medium to high	7.5-8.0	2.63-2.80	Double	1.58	Synthetic spinel, blue topaz	Double refraction, refractive index.
Emerald	do.	Green	Medium	Very high	7.5	2.63-2.80	do.	1.58	Fused emerald, glass, tourmaline, peridot, green garnet, doublets	Emerald filter, dichroism, refractive index.
Emerald, synthetic	do.	do.	Small	High	7.5-8.0	2.63-2.80	do.	1.58	Genuine emerald	Flaws, brilliant, fluorescence in ultra-violet light.
Golden	do.	Yellow to golden	Any	Low to medium	7.5-8.0	2.63-2.80	do.	1.58	Citrine, topaz, glass, doublets	
Morganite	do.	Pink to rose	Any	do.	7.5-8.0	2.63-2.80	do.	1.58	Kunzite, tourmaline, pink sapphire	Refractive index.
Calcite:										
Marble	Calcium carbonate	White, pink, red, blue, green, or brown	Any	Low	3.0	2.72	Double (strong)	1.49-1.66	Silicates, banded agate, alabaster gypsum	Translucent.
Mexican onyx	do.	do.	Any	Low	3.0	2.72	do.	1.6	do.	Banded, translucent.
Chrysoberyl:										
Alexandrite	Beryllium aluminate	Green by day, red by artificial light	U.S.S.R. (small), Sri Lanka (medium)	High	8.5	3.50-3.84	Double	1.75	Synthetic	Dichroism, inclusions in synthetic sapphire.

See footnotes at end of table.

TABLE 3—Continued
GUIDE TO SELECTED GEMSTONES AND GEM MATERIALS USED IN JEWELRY

Name	Composition	Color	Practical size ¹	Cost ²	Mohs	Specific gravity	Refraction	Refractive index	May be confused with-	Recognition characters
Chrysoberyl—Continued:										
Catseye	Beryllium aluminate	Greenish to brownish	Small to large	High	8.5	3.50-3.84	Double	1.75	Synthetic, shell	Gravity and translucence.
Chrysolite	do.	Yellow, green, and/or brown	Medium	Medium	8.5	3.50-3.84	do.	1.75	Tourmaline, peridot	Refractive index, silky.
Coral	Calcium carbonate	Orange, red, white, black, or green	Branching, medium	Low	3.5-4.0	2.6-2.7	do.	1.49-1.66	False coral	Dull translucent.
Corundum:										
Ruby	Aluminum oxide	Rose to deep purplish red	Small	Very high	9.0	3.95-4.10	do.	1.78	Synthetics, including spinel	Inclusions, fluorescence.
Sapphire	do.	Blue	Medium	High	9.0	3.95-4.10	do.	1.78	do.	Inclusions, double refraction, dichroism.
Sapphire, fancy	do.	Yellow, pink, white, orange, green, or violet	Medium to large	Medium	9.0	3.95-4.10	do.	1.78	Synthetics, glass and doublets	Inclusions, double refraction, refractive index.
Sapphire and ruby stars	do.	Red, pink, violet blue, or gray	do.	High to low	9.0	3.95-4.10	do.	1.78	Star quartz, synthetic stars	Shows asterism, color on side view.
Sapphire or ruby synthetic	do.	Yellow, pink, or blue	Up to 20 carats	Low	9.0	3.95-4.10	do.	1.78	Synthetic spinel, glass	Curved striae, bubble inclusions.
Diamond	Carbon	White, blue-white, yellow, brown, green, pink, blue	Any	Very high	10.0	3.516-3.525	Single	2.42	Zircon, titania, cubic zirconia	High index, dispersion, single refraction, hardness, cut, luster.

See footnotes at end of table.

TABLE 3—Continued
GUIDE TO SELECTED GEMSTONES AND GEM MATERIALS USED IN JEWELRY

Name	Composition	Color	Practical size ¹	Cost ²	Mohs	Specific gravity	Refraction	Refractive index	May be confused with-	Recognition characters
Feldspar:										
Amazonstone	Alkali aluminum-silicate	Green	Large	Low	6.0-6.5	2.56	—	1.52	Jade	Cleavage, sheen, vitreous to pearly, opaque, grid.
Labradorite	Alkali aluminum-silicate	Gray with blue and bronze sheen color play	Large	Low	6.0-6.5	2.56	—	1.56	Jade	Cleavage, sheen, vitreous to pearly opaque, grid.
Moonstone	do.	White	do.	Low	6.0-6.5	2.77	—	1.52-1.54	Glass or white onyx	Blue sheen, opalescent.
Garnet	Complex silicate	Brown, black, yellow, green, ruby red, or orange	Small to medium	Low to high	6.5-7.5	3.15-4.30	Single strained	1.79-1.98	Synthetics, spinel, glass	Single refraction, anomalous strain.
Jade:										
Jadeite	do.	Green, yellow, black, white, or mauve	Large	Low to very high	6.5-7.0	3.3-3.5	Cryptocrystalline	1.65-1.68	Onyx, bowenite, vesuvianite, grossularite	Luster, spectrum, translucent to opaque.
Nephrite	Complex hydrous silicate	do.	do.	do.	6.0-6.5	2.96-3.10	do.	1.61-1.63	do.	Do.
Peridot	Iron magnesium silicate	Yellow and/or green	Any	Medium	6.5-7.0	3.27-3.37	Double (strong)	1.65-1.69	Tourmaline chrysoberyl	Strong double refraction, low dichroism.
Opal	Hydrous silica	Colors flash in white gray, black, red, or yellow	Large	Low to high	5.5-6.5	1.9-2.3	Isotropic	1.45	Glass, synthetics, triplets	Play of color.
Pearl	Calcium carbonate	White, pink, or black	Small	do.	2.5-4.0	2.6-2.85	—	—	Cultured and imitation	Luster, structure, X-ray.

See footnotes at end of table.

TABLE 3—Continued
GUIDE TO SELECTED GEMSTONES AND GEM MATERIALS USED IN JEWELRY

Name	Composition	Color	Practical size ¹	Cost ²	Mohs	Specific gravity	Refraction	Refractive index	May be confused with-	Recognition characters
Quartz:										
Agate	Silica	Any color	Large	Low	7.0	2.58-2.64	—	—	Glass, plastic, Mexican onyx	Cryptocrystalline, irregularly banded, dendritic inclusions.
Amethyst	do.	Purple	do.	Medium	7.0	2.65-2.66	Double	1.55	do.	Refractive index, double refraction, transparent.
Cairngorm	do.	Smoky	do.	Low	7.0	2.65-2.66	do.	1.55	do.	Do.
Citrine	do.	Yellow	do.	Low	7.0	2.65-2.66	do.	1.55	do.	Do.
Crystal, rock	do.	Colorless	do.	Low	7.0	2.65-2.66	do.	1.55	do.	Do.
Jasper	do.	Uniform or spotted red, yellow, or green	do.	Low	7.0	2.58-2.66	—	—	do.	Opaque, vitreous.
Onyx	do.	Many colors	do.	Low	7.0	2.58-2.64	—	—	do.	Uniformly banded.
Rose	do.	Pink, rose red	do.	Low	7.0	2.65-2.66	Double	1.55	do.	Refractive index, double refraction, translucent.
Spinel	Magnesium aluminum oxide.	Any	Small to medium	Medium	8.0	3.5-3.7	Single	1.72	Synthetic, garnet	Refractive index, single refraction, inclusions.
Spinel, synthetic	do.	Any	Up to 40 carats	Low	8.0	3.5-3.7	Double	1.73	Spinel, corundum, beryl, topaz, alexandrite	Weak double refraction, curved striae, bubbles.
Spodumene:										
Kunzite	Lithium aluminum silicate	Pink to lilac	Medium	Medium	6.5-7.0	3.13-3.20	Double	1.66	Amethyst, morganite	Refractive index.

See footnotes at end of table.

TABLE 3—Continued
GUIDE TO SELECTED GEMSTONES AND GEM MATERIALS USED IN JEWELRY

Name	Composition	Color	Practical size ¹	Cost ²	Mohs	Specific gravity	Refraction	Refractive index	May be confused with-	Recognition characters
Spudumene— Continued:										
Hiddenite	Lithium aluminum silicate	Yellow to green	Medium	Medium	6.5-7.0	3.13-3.20	Double.	—	Synthetic spinel	Refractive index.
Tanzanite	Complex silicate	Blue	Small	High	6.0-7.0	3.30	do.	1.69	Sapphire, synthetics	Strong trichroism.
Topaz	do.	White, blue, green	Medium	Low to medium	8.0	3.4-3.6	do.	1.62	Beryl, quartz	Refractive index.
Tourmaline	do.	All, including mixed	do.	do.	7.0-7.5	2.98-3.20	do.	1.63	Glass, plastics	Difficult if matrix not present, matrix usually limonitic.
Turquoise	Copper aluminum phosphate	Blue to green phosphate	Large	Low	6.0	2.60-2.83	do.	1.63	Glass, plastics	Difficult if matrix not present, matrix usually limonitic.
Zircon	Zirconium silicate	White, blue, or brown, yellow, or green	Small to medium	Low to medium	6.0-7.5	4.0-4.8	Double (strong)	1.79-1.98	Diamond, synthetics, topaz, aquamarine	Double refraction, strongly dichroic, wear on facet edges.

¹Small—up to 5 carats; medium—up to 50 carats; large—more than 50 carats.

²Low—up to \$25 per carat; medium—up to \$200 per carat; high—more than \$200 per carat.

**TABLE 4
SYNTHETIC GEMSTONE PRODUCTION METHODS**

Gemstone	Production methods	Company	Date of first production
Ruby	Flux	Chatham	1950's
Do.	do.	Kashan	1960's
Do.	do.	Knischka	1980's
Do.	do.	J.O. Crystal (Ramaura)	1980's
Do.	Zone melt	Seiko	1980's
Do.	Melt pulling	Kyocera (Inamori)	1970's
Do.	Verneuil	Various producers	1900's
Star ruby	do.	Linde (Div. of Union Carbide)	1940's
Do.	Melt pulling	Kyocera	1980's
Do.	do.	Nakazumi	1980's
Sapphire	Flux	Chatham	1970's
Do.	Zone melt	Seiko	1980's
Do.	Melt pulling	Kyocera	1980's
Do.	Verneuil	Various producers	1900's
Star sapphire	Verneuil	Linde	1940's
Emerald	Flux	Chatham	1930's
Do.	do.	Gilson	1960's
Do.	do.	Kyocera	1970's
Do.	do.	Seiko	1980's
Do.	do.	Lennix	1980's
Do.	do.	U.S.S.R.	1980's
Do.	Hydrothermal	Lechleitner	1960's
Do.	do.	Regency	1980's
Do.	do.	Biron	1980's
Do.	do.	U.S.S.R.	1980's
Alexandrite	Flux	Creative crystals	1970's
Do.	Melt pulling	Kyocera	1980's
Do.	Zone melt	Seiko	1980's
Cubic zirconia	Skull melt	Various producers	1970's

**TABLE 5
VALUE OF 1991 U.S.
GEMSTONE PRODUCTION,
BY GEM MATERIALS**

Gem materials	Value
Agate	\$535,000
Beryl	450,000
Coral (all types)	63,000
Garnet	251,000
Gem feldspar	1,485,750
Geode/nodes	769,640
Fire agate	194,100
Jasper	236,300
Obsidian	18,000
Opal	579,300
Peridot	1,757,000
Petrified wood	462,500
Quartz	5,197,300
Sapphire/ruby	3,282,000
Topaz	126,600
Tourmaline	629,000
Turquoise	610,800
Total	16,647,290

TABLE 6
PRICES OF U.S. CUT DIAMONDS, BY SIZE AND QUALITY

Carat weight	Description, color ¹	Clarity ² (GIA terms)	Price range per carat ³		Average ⁴ July 1991
			Jan. 1990	Jan. 1991	
0.25	G	VS1	\$1,400	-\$1,400	\$1,400
.25	G	VS2	1,200	-1,200	1,200
.25	G	SII	970	-970	970
.25	H	VS1	1,200	-1,200	1,200
.25	H	VS2	1,100	-1,100	1,100
.25	H	SII	950	-950	950
.50	G	VS1	2,700	-2,700	2,700
.50	G	VS2	2,500	-2,500	2,500
.50	G	SII	2,300	-2,300	2,300
.50	H	VS1	2,600	-2,600	2,600
.50	H	VS2	2,400	-2,400	2,400
.50	H	SII	2,100	-2,100	2,100
.75	G	VS1	3,500	-3,500	3,500
.75	G	VS2	3,200	-3,200	3,200
.75	G	SII	2,800	-2,800	2,800
.75	H	VS1	3,000	-3,000	3,000
.75	H	VS2	2,700	-2,700	2,700
.75	H	SII	2,500	-2,500	2,500
1.00	G	VS1	4,600	-4,600	4,600
1.00	G	VS2	4,100	-4,100	4,100
1.00	G	SII	3,500	-3,500	3,500
1.00	H	VS1	4,100	-4,100	4,100
1.00	H	VS2	3,600	-3,600	3,600
1.00	H	SII	3,200	-3,200	3,200

¹Gemological Institute of America (GIA) color grades: D—colorless; E—rare white; G-H—I—traces of color.
²Clarity: IF—no blemishes; VVS1—very, very slightly included; VS—very slightly included; VS2—very slightly included, but not visible; SII—slightly included.
³Jeweler's Circular-Keystone, V. 163, No. 3, Feb. 1991.
⁴Jeweler's Circular-Keystone, V. 162, No. 9, Sept. 1991.

TABLE 7
PRICES OF U.S. CUT COLORED GEMSTONES, BY SIZE¹

Gemstone	Carat weight	Price range per carat in 1991 ²	Average price per carat ²	
			Oct. 1990	Oct. 1991
Amethyst	1	\$6 - \$18	\$13.00	\$13.00
Aquamarine	1	100 - 250	175.00	175.00
Emerald	1	1,900 - 3,500	2,750.00	2,750.00
Garnet, tsavorite	1	500 - 800	750.00	750.00
Ruby	1	3,000 - 4,000	3,500.00	3,900.00
Sapphire	1	800 - 2,000	1,400.00	1,400.00
Tanzanite	1	250 - 350	262.50	210.00
Topaz	1	6 - 12	9.00	9.00
Tourmaline, red	1	60 - 125	92.50	92.50

¹Fine quality.
²Jeweler's Circular-Keystone, V. 162, No. 12, Oct. 1991, p. 119. These figures represent a sampling of net prices that wholesale colored stone dealers in various U.S. cities charged their cash customers during the month for fine-quality stones.

TABLE 8
U.S. EXPORTS AND REEXPORTS OF DIAMOND (EXCLUSIVE OF INDUSTRIAL DIAMOND), BY COUNTRY

Country	1990 ^a		1991	
	Quantity (carats)	Value ^b (millions)	Quantity (carats)	Value ^b (millions)
Exports and reexports:				
Belgium	305,621	\$274.0	787,290	\$341.7
Canada	81,072	40.8	303,492	32.0
France	9,280	14.7	8,746	23.7
Hong Kong	163,591	316.5	118,966	267.6
Israel	254,240	222.3	260,924	238.3
Japan	110,024	283.6	107,285	195.5
Singapore	4,766	20.2	19,550	27.5
Switzerland	82,937	131.6	43,456	143.3
Thailand	53,327	45.5	35,019	39.3
United Kingdom	83,358	47.2	12,682	37.6
Other	67,204	36.2	142,173	36.1
Total	1,215,420	1,432.6	1,839,583	^c1,382.7

^aRevised.

^bCustoms value.

^cData do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF DIAMOND, BY KIND, WEIGHT, AND COUNTRY

Kind, range, and country of origin	1990		1991	
	Quantity (carat)	Value ¹ (millions)	Quantity (carat)	Value ¹ (millions)
Rough or uncut, natural:²				
Belgium	104,544	\$26.1	455,621	\$40.7
Brazil	10,547	1.2	106,396	9.8
Israel	11,769	5.4	17,097	10.3
Netherlands	5,552	12.1	18,334	9.2
South Africa, Republic of	458	1.3	13,787	7.6
Switzerland	1,653	3.6	64,717	18.9
United Kingdom	300,579	287.1	625,965	249.5
Venezuela	8,423	.5	20,580	.3
Other	779,530	234.4	460,339	181.1
Total	1,223,055	\$570.7	1,782,836	\$274.4
Cut but unset, not more than 0.5 carat:				
Belgium	769,047	326.9	789,422	280.1
Brazil	17,168	6.1	41,626	17.6
Canada	7,232	1.0	4,419	1.2
Hong Kong	176,077	45.4	132,735	29.0
India	2,946,261	768.8	3,373,905	825.4
Israel	471,820	224.0	727,175	357.9
Netherlands	4,363	2.4	5,612	1.7
South Africa, Republic of	8,326	7.5	16,517	10.0
Switzerland	12,894	4.7	21,237	6.2
United Kingdom	5,593	1.9	1,424	.7
Other	80,997	39.8	86,601	20.9
Total	4,499,778	1,428.5	5,200,673	1,550.7
Cut but unset, more than 0.5 carat:				
Belgium	516,109	651.1	592,530	793.9
Hong Kong	15,811	32.8	14,196	34.5
India	181,619	113.0	41,316	33.8
Israel	983,684	942.0	783,799	834.4
Netherlands	10,844	24.9	4,491	13.8
South Africa, Republic of	5,792	11.5	5,291	12.2
Switzerland	14,484	70.3	23,766	115.2
United Kingdom	28,288	52.6	9,018	34.8
Other	48,550	57.7	23,553	41.3
Total	1,805,181	1,955.9	1,497,960	1,913.9

¹Revised.

¹Customs value.

²Includes some natural advanced diamond.

Source: Bureau of the Census.

TABLE 10
U.S. IMPORTS FOR CONSUMPTION OF GEMSTONES, OTHER THAN DIAMOND, BY KIND AND COUNTRY

Kind and country	1990		1991	
	Quantity (carats)	Value ¹ (millions)	Quantity (carats)	Value ¹ (millions)
Emerald:				
Belgium	21,217	\$1.1	10,782	\$1.6
Brazil	1,189,248	6.3	1,554,717	6.7
Colombia	382,051	58.2	212,818	51.5
France	10,202	2.5	7,456	3.0
Germany, Federal Republic of	44,811	2.1	19,828	2.2
Hong Kong	156,111	13.2	114,521	13.4
India	1,317,886	24.7	1,298,384	22.7
Israel	93,973	20.6	134,178	21.3
Japan	2,769	.2	2,946	.7
South Africa, Republic of	52	(²)	206	0.3
Switzerland	144,394	18.9	66,283	23.3
Taiwan	4,533	.2	414	.1
Thailand	291,458	7.4	483,037	12.6
United Kingdom	9,722	2.6	8,755	.9
Other	51,962	4.3	24,980	5.1
Total³	3,720,389	162.4	3,939,305	165.5
Ruby:				
Belgium	4,250	.4	8,127	1.3
Brazil	1,562	.1	11,517	.5
Colombia	346	.1	145	(²)
France	3,340	2.2	4,686	.9
Germany, Federal Republic of	11,580	.8	15,438	1.6
Hong Kong	49,175	5.3	38,030	4.4
India	313,583	2.3	455,938	1.9
Israel	12,857	1.1	10,736	.8
Japan	13	(²)	647	.1
Switzerland	190,056	26.6	72,979	16.5
Thailand	1,323,506	46.6	1,715,511	37.3
United Kingdom	66,831	6.5	12,089	3.2
Other	42,991	6.3	32,128	2.4
Total³	2,020,090	98.4	2,377,971	70.9
Sapphire:				
Australia	3,013	.2	3,963	.3
Austria	202	(²)	603	(²)
Belgium	14,131	.5	5,044	1.3
Brazil	2,827	.1	7,932	.4
Canada	2,126	.2	8,109	.4
Colombia	1,328	(²)	111	(²)
France	2,409	1.9	4,695	1.3
Germany, Federal Republic of	44,834	.9	21,882	.8
Hong Kong	83,519	3.9	141,486	6.2
India	101,510	.8	59,588	.6
Israel	26,140	1.5	10,723	.8
Japan	7,666	.1	6,536	.5
Korea, Republic of	204	(²)	1,980	(²)

See footnotes at end of table.

TABLE 10—Continued
U.S. IMPORTS FOR CONSUMPTION OF GEMSTONES, OTHER THAN DIAMOND, BY KIND AND COUNTRY

Kind and country	1990		1991	
	Quantity (carats)	Value ¹ (millions)	Quantity (carats)	Value ¹ (millions)
Sapphire—Continued:				
Singapore	4,931	\$0.6	833	\$0.4
Thailand	3,248,891	51.2	3,122,987	46.1
United Kingdom	11,135	1.8	15,895	1.4
Other	44,113	1.6	14,062	.9
Total³	3,796,764	81.9	3,501,548	81.5
Other:				
Rough, uncut:				
Australia		1.7		1.1
Brazil		41.5		35.2
Colombia		2.4		1.4
Hong Kong		2.0		2.0
Nigeria		.1		.2
Pakistan	NA	.4	NA	.7
South Africa, Republic of		.4		.6
Switzerland		3.5		1.0
United Kingdom		.4		1.2
Zambia		1.3		.8
Other		15.9		11.8
Total	NA	67.9	NA	56.0
Cut, set and unset:				
Australia		6.1		3.2
Brazil		8.6		9.3
Canada		.4		.2
China		1.4		.8
Germany, Federal Republic of		19.5		15.2
Hong Kong		17.6		16.4
India	NA	5.6	NA	7.4
Japan		10.0		9.3
Switzerland		1.7		1.1
Taiwan		3.1		2.8
Thailand		40.9		72.3
United Kingdom		2.1		2.1
Other		19.8		14.4
Total³	NA	136.8	NA	154.7

¹Revised. NA Not available.

²Customs value.

³Less than 1/10 unit.

⁴Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 11
VALUE OF U.S. IMPORTS OF
SYNTHETIC AND IMITATION
GEMSTONES, INCLUDING
PEARLS, BY COUNTRY

(Million dollars¹)

Country	1990	1991
Synthetic, cut but unset:		
Austria	3.6	3.4
France	.8	1.9
Germany, Federal Republic of	9.6	8.7
Japan	.6	.7
Korea, Republic of	5.5	4.9
Switzerland	3.1	2.8
Thailand	7.0	16.0
Other	2.4	4.4
Total	32.6	42.8
Imitation:		
Austria	53.9	58.7
Czechoslovakia	1.9	4.1
Germany, Federal Republic of	1.6	1.8
Japan	2.0	1.5
Other	5.0	3.0
Total	64.4	69.1

¹Revised.

¹Customs value.

Source: Bureau of the Census.

TABLE 12
U.S. IMPORTS FOR CONSUMPTION OF GEMSTONES

(Thousand carats and thousand dollars)

Stones	1990		1991	
	Quantity	Value ¹	Quantity	Value ¹
Diamonds:				
Rough or uncut	1,223	570,750	1,783	527,424
Cut but unset	6,305	3,384,472	6,699	3,464,599
Emeralds: Cut but unset	3,720	162,375	3,939	165,508
Coral and similar materials, unworked	2,792	7,504	2,556	6,746
Rubies and sapphires: Cut but unset	5,817	180,375	5,880	152,475
Pearls:				
Natural	NA	3,734	NA	4,525
Cultured	NA	19,097	NA	16,753
Imitation	NA	3,814	NA	2,459
Other precious and semiprecious stones:				
Rough, uncut	NA	55,436	NA	43,825
Cut, set and unset	NA	113,949	NA	133,376
Other	NA	6,727	NA	5,404
Synthetic:				
Cut but unset	113,367	32,649	148,173	42,820
Other	NA	1,911	NA	2,094
Imitation gemstone	NA	60,594	NA	66,649
Total²	XX	4,603,388	XX	4,634,656

¹Revised. NA Not available. XX Not applicable.

¹Customs value.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 13
DIAMOND: WORLD PRODUCTION, BY TYPE AND COUNTRY¹

(Thousand carats)

Country	1987			1988			Synthetic	1989			Synthetic
	Gem ²	Natural industrial	Total	Gem ²	Natural industrial	Total		Gem ²	Natural industrial	Total	
Angola ^a	180	10	190	950	50	1,000	—	1,165	80	1,245	—
Australia	13,650	16,683	30,333	17,413	17,413	34,826	—	17,540	17,540	35,080	—
Botswana	9,368	3,840	13,208	10,660	4,569	15,229	—	10,676	4,576	15,252	—
Brazil	300	200	500	353	180	533	—	350	150	500	—
Central African Republic	304	108	412	284	59	343	—	334	81	415	—
China ^a	200	800	1,000	200	800	1,000	15,000	200	800	1,000	15,000
Côte d'Ivoire ^{a, 5}	15	6	21	8	3	11	—	9	3	12	—
Czechoslovakia ^a	—	—	—	—	—	—	5,000	—	—	—	5,000
France ^a	—	—	—	—	—	—	4,000	—	—	—	4,000
Ghana ⁶	65	400	465	78	181	259	—	86	201	287	—
Greece ^a	—	—	—	—	—	—	1,000	—	—	—	1,000
Guinea ⁶	163	12	175	136	10	146	—	138	10	148	—
Guyana	2	5	7	1	3	4	—	3	5	8	—
India	16	3	19	11	3	4	—	3	12	15	—
Indonesia ^a	7	22	29	7	22	29	—	7	25	32	—
Ireland ^a	—	—	—	—	—	—	60,000	—	—	—	60,000
Japan ^a	—	—	—	—	—	—	25,000	—	—	—	25,000
Liberia	112	183	295	67	100	167	—	62	93	155	—
Namibia	971	50	1,021	890	48	938	—	910	17	927	—
Romania ^a	—	—	—	—	—	—	5,000	—	—	—	4,500
Sierra Leone ⁵	150	75	225	12	6	18	—	90	39	129	—
South Africa, Republic of:											
Finsch Mine	1,455	2,701	4,156	1,372	2,548	3,920	—	1,613	2,997	4,610	—
Premier Mine	772	1,713	2,485	696	1,543	2,239	—	689	1,526	2,215	—
Other De Beers' properties ⁷	1,427	546	1,973	1,388	531	1,919	—	1,360	520	1,880	—
Other	409	30	439	361	65	426	—	348	63	411	—
Total	4,063	4,990	9,053	3,817	4,687	8,504	55,000	4,010	5,106	9,116	60,000
Swaziland	48	32	80	44	29	73	—	33	22	55	—
Sweden ^a	—	—	—	—	—	—	25,000	—	—	—	25,000
Tanzania	87	37	124	60	26	86	—	53	23	76	—
U.S.S.R. ^a	7,400	7,400	14,800	7,500	7,500	15,000	41,500	7,500	7,500	15,000	41,500
United States	—	—	—	—	—	—	W	—	—	—	W
Venezuela	38	68	106	54	74	128	—	70	185	255	—
Yugoslavia ^a	—	—	—	—	—	—	5,000	—	—	—	5,000
Zaire	3,885	15,540	19,425	2,724	15,439	18,163	—	2,663	15,092	17,755	—
Total	41,024	50,464	91,488	45,269	51,202	96,471	241,500	45,902	51,560	97,462	246,000

See footnotes at the end of table

TABLE 13—Continued
DIAMOND: WORLD PRODUCTION, BY TYPE AND COUNTRY¹

(Thousand carats)

Country	1990				1991 ^a			
	Gem ²	Natural industrial	Total	Synthetic	Gem ²	Natural industrial	Total	Synthetic
Angola ^a	'1,215	'85	'1,300	—	1,215	85	1,300	—
Australia	17,331	17,331	34,662	—	17,978	17,978	'35,956	—
Botswana	12,146	5,206	17,352	—	12,000	6,000	18,000	—
Brazil	'600	'900	'1,500	—	600	900	1,500	—
Central African Republic	'303	'78	'381	—	300	70	370	—
China ^a	200	800	1,000	15,000	200	800	1,000	15,000
Côte d'Ivoire ^{a, 5}	9	3	12	—	11	4	15	—
Czechoslovakia ^a	—	—	—	5,000	—	—	—	5,000
France ^a	—	—	—	4,000	—	—	—	4,000
Ghana ⁶	'191	'446	'637	—	210	490	700	—
Greece ^a	—	—	—	1,000	—	—	—	1,000
Guinea ⁶	130	5	'135	—	85	6	'91	—
Guyana	3	5	8	—	3	5	8	—
India	3	12	'15	—	3	12	15	—
Indonesia ^a	7	23	'30	—	8	24	32	—
Ireland ^a	—	—	—	60,000	—	—	—	60,000
Japan ^a	—	—	—	25,000	—	—	—	30,000
Liberia	40	60	'100	—	40	60	100	—
Namibia	'745	'16	'761	—	1,170	24	'1,194	—
Romania ^a	—	—	—	4,500	—	—	—	4,500
Sierra Leone ⁵	'66	'12	'78	—	175	68	'243	—
South Africa, Republic of:								
Finsch Mine	1,462	2,716	4,178	—	1,500	2,500	4,000	—
Premier Mine	724	1,604	2,328	—	700	1,500	2,200	—
Other De Beers ⁷ properties ⁷	1,240	474	1,714	—	1,200	500	1,700	—
Other	400	'88	'488	—	400	112	512	—
Total	3,826	'4,882	'8,708	'60,000	3,800	'4,612	'8,412	60,000
Swaziland	'25	'17	'42	—	18	12	30	—
Sweden ^a	—	—	—	25,000	—	—	—	25,000
Tanzania	'59	'26	'85	—	56	24	80	—
U.S.S.R. ^a	7,500	7,500	15,000	41,000	7,500	7,500	15,000	60,000
United States	—	—	—	W	—	—	—	90,000
Venezuela	88	245	333	—	90	250	340	—
Yugoslavia ^a	—	—	—	5,000	—	—	—	5,000
Zaire	'2,914	'16,513	'19,427	—	3,000	17,000	20,000	—
Total	'47,401	'54,165	'101,566	245,500	48,462	55,924	104,386	359,500

^aEstimated. ²Revised. W Withheld to avoid disclosing company proprietary data.

¹Table includes data available through May 19, 1992. Total diamond output (gem plus industrial) for each country actually is reported, except where indicated by a footnote to be estimated. In contrast, the detailed separate production data for gem diamond and industrial diamond are U.S. Bureau of Mines estimates except for Australia (1987), Brazil (1987-90), and Central African Republic (1987-90), for which source publications give details on grade as well as totals. The estimated distribution of total output between gem and industrial diamond is conjectural, and for most countries, is based on the best available data at time of publication.

²Includes near-gem and cheap-gem qualities.

³Includes all synthetic diamond production.

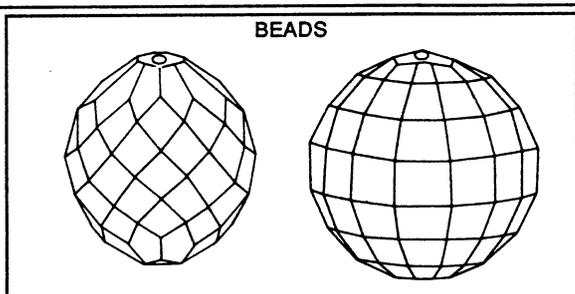
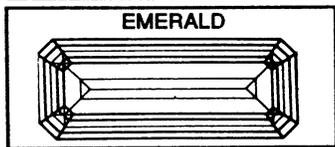
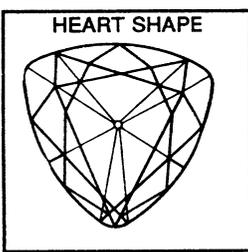
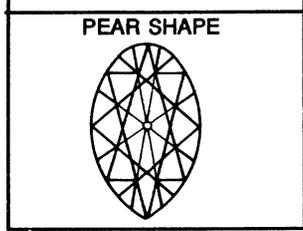
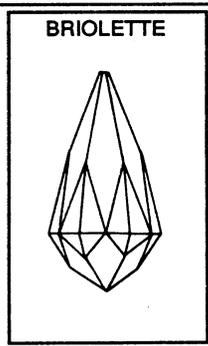
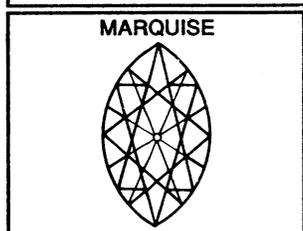
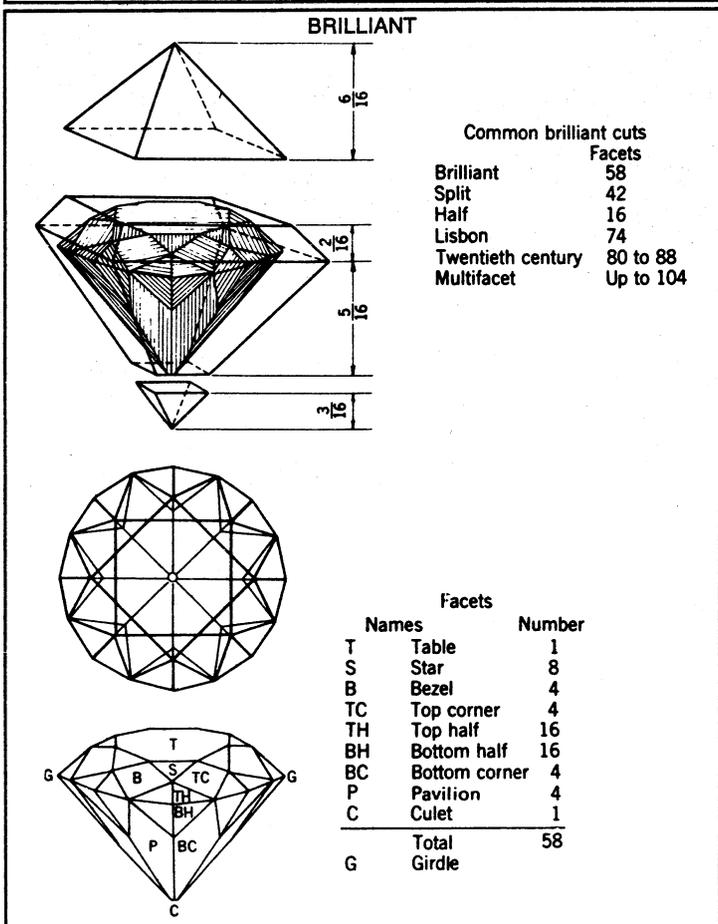
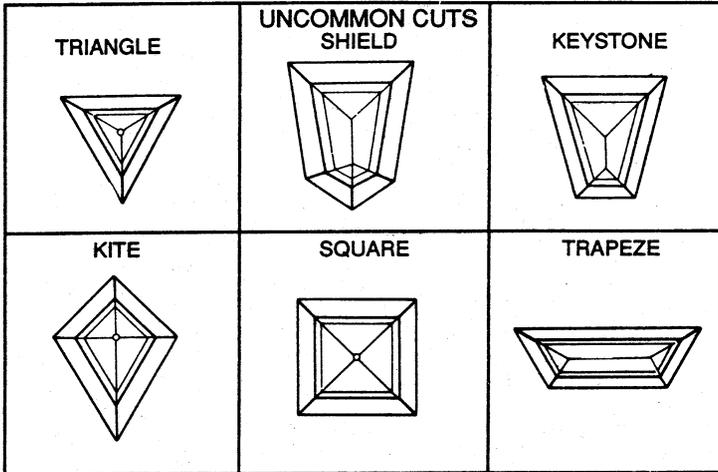
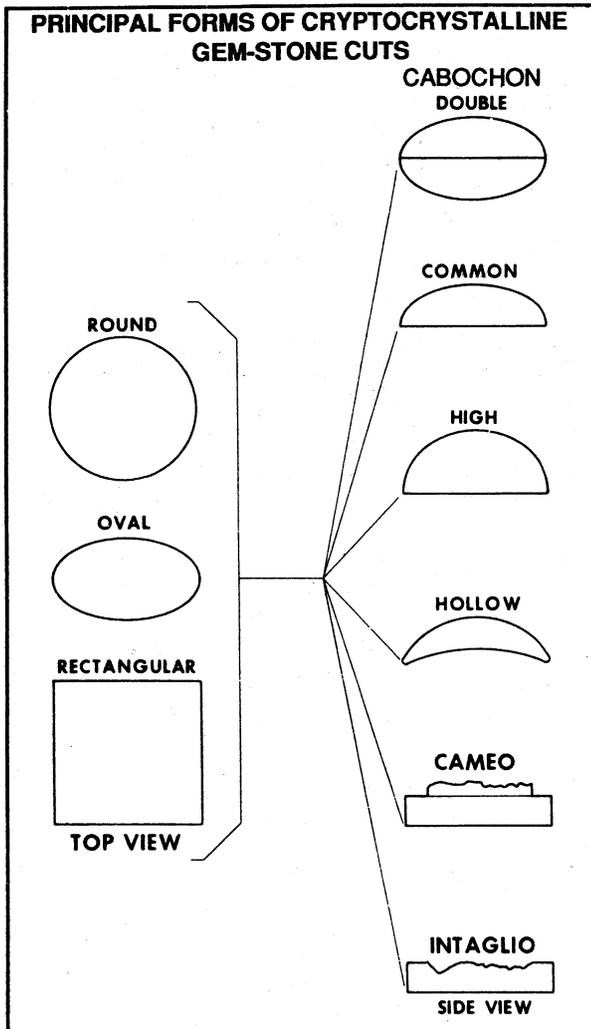
⁴Reported figure.

⁵Figures are estimates based on reported exports and do not include smuggled diamonds.

⁶Figures do not include smuggled artisanal production.

⁷Other De Beers' Group output from the Republic of South Africa includes Kimberley Pool, Koffiefontein Mine, Namaqualand mines, and Venetia mines.

FIGURE 1
 PRINCIPAL FORMS OF CRYPTOCRYSTALLINE AND CRYSTALLINE GEMSTONE CUTS



PRINCIPAL FORMS OF CRYSTALLINE GEMSTONE CUTS

GERMANIUM

By Thomas O. Llewellyn

Mr. Llewellyn, a physical scientist with more than 30 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for germanium since 1987. Domestic survey data were prepared by Tony E. Morris, statistical assistant.

The estimated domestic refinery production and consumption of germanium in 1991 were about 17% and 3%, respectively, below the levels of 1990. The lower production and consumption resulted mainly by a considerable reduction in defense infrared systems requirements.

DOMESTIC DATA COVERAGE

Domestic refinery production and consumption data for germanium are estimated by the U.S. Bureau of Mines based on discussions with domestic producers.

BACKGROUND

Germanium is recovered as a minor byproduct of the refining of base metal ores, and the potential supply of this metal, which is dependent on the level of zinc production, has historically exceeded demand.

Invention and development of the germanium transistor opened the path for the solid-state electronic field and, from 1950 through the early 1970's, provided an excellent market for germanium. Despite the continued growth of the electronics industry in the 1970's, germanium demand for transistors, diodes, and rectifiers declined because germanium was being replaced by electronic-grade silicon. However, the reduced demand for germanium in the electronics field was offset by a dramatic increase in demand for germanium in both infrared night vision systems and fiber-optic communication networks.

Definition, Grades, and Specifications

Germanium has a metallic appearance and is grayish white in color and lustrous, hard, and very brittle. It is a semiconductor, with electrical properties between those of a metal and an insulator. The National Stockpile Purchase Specification P-114-R, December 16, 1989, for intrinsic germanium metal specifies an electrical resistivity of 50 ohm-centimeter at 20°C (40 ohm-centimeter at 25°C) over the entire ingot length.

Germanium is available commercially as a tetrachloride and high-purity oxide and in the form of zone-refined ingots, single-crystal bars, castings, doped semiconductors, optical materials, optical blanks, and other specialty products.

Industry Structure

Most germanium occurs as a minor constituent of certain base metal ores and coal deposits. Those producers that currently recover primary germanium for the most part depend on germanium-rich residues, mainly from zinc derived from past or present base metal smelting operations.

In the United States, Eagle-Picher Industries Inc.'s Quapaw, OK, Specialty Materials Div. has the capability of recovering primary germanium from zinc smelter residues. Eagle-Picher also reprocessed scrap. Kawecki Berylco Industries Inc., a division of Cabot Corp. in Revere, PA, and Atomergic Chemetals Corp., Plainview, NY, produced germanium from reprocessed scrap and semirefined foreign material.

The Jersey Miniere Zinc Co. in Clarksville, TN, continued to produce germanium-rich residues as a byproduct of processing zinc ores from its Elmwood-Gordonville Mines. These residues were shipped to Metallurgie Hoboken-Overpelt S.A. (MHO) in Belgium for germanium recovery and refining.

Little information was available on the financial structure of U.S. and world germanium industries. Germanium refiners usually were involved in the production and sale of many different metals and specialty products.

Geology-Resources

Minerals in which germanium is concentrated are germanite, a sulfoarsenite of copper, germanium, and iron with an average content of 5% germanium; argyrodite, a double sulfide of germanium and silver containing 5% to 7% germanium; renierite, a complex sulfide of arsenic, copper, germanium, iron, tin, and zinc with 6% to 8% germanium; and several other minerals such as canfieldite, itoite, stottite, and ultrabasite. Primary germanium minerals are normally formed in sulfide mineralization processes at low-to-intermediate temperatures, and secondary varieties may result from supergene alteration of sulfide ore deposits.¹

Currently, there are two major reserves of germanium in the United States. The largest is the recoverable germanium that occurs as a minor constituent of zinc sulfide ores in the middle Tennessee zinc district. The other major reserve of germanium is in

southern Utah. Here the germanium is found in the iron oxide ore zone of a depleted copper mine.

There are no reliable germanium assay data available for many areas of the world. The U.S. and world resources could be expanded if germanium were to be recovered from ash and flue dusts resulting from burning of certain coals for power generation.

Technology

Germanium is obtained commercially as a byproduct of base metal refining. Improvements have been made, but the basic processes have remained virtually unchanged.

Regardless of the source, germanium raw materials are reacted with concentrated hydrochloric acid to form germanium tetrachloride, which is then purified by fractional distillation. The purified germanium tetrachloride is hydrolyzed with water to produce germanium dioxide, which is removed by filtration and dried. Dried germanium dioxide is reduced with hydrogen at about 760° C to a germanium metal powder, which is then melted and cast into metal bars. These bars are then zone-refined to produce intrinsic-grade metal. This high-purity metal is mainly used for electronic and infrared optics. Zone refining produces polycrystalline germanium.²

Certain applications of germanium, such as gamma-ray detectors, require single-crystal germanium. Single crystals are produced by two methods, the horizontal pulling process or the vertical pulling process, also known as the Czochralski method.

More than 50% of the metal used during the manufacture of most electronic and optical devices is recycled as new scrap. As a result of the low unit use of germanium in microelectronic devices, very little germanium returns as old scrap.

Substitutes

Less expensive silicon substitutes for germanium in certain electronic

applications. Certain bimetallic compounds of gallium, indium, selenium, and tellurium can also substitute for germanium. Germanium is more reliable in some high-frequency and high-power applications and more economical as a substrate for some light-emitting diode applications. In infrared guidance systems, zinc selenide or germanium glass substitutes for germanium metal, but at the expense of performance.

Economic Factors

Table 1 shows import duties for germanium products, which became effective on January 1, 1989, under the new Harmonized Tariff Schedule of the United States. Domestic producers are granted a depletion allowance of 14% on both domestic and foreign production of germanium. (See table 1.)

Operating Factors

Germanium has little or no effect upon the environment because it usually occurs only as a trace element in some ores and carbonaceous materials. The small quantities used in commercial applications also pose no threat to the environment. Germanium compounds generally have a low order of toxicity, except for germanium tetrahydride, which is considered toxic.

Based on a 1976 report, the energy requirements for the production of zone-refined germanium metal from zinc sulfide concentrates and scrap is 2,145 million British thermal units per net ton of germanium ingot.³

ANNUAL REVIEW

Strategic Considerations

The importance of germanium as a strategic and critical material was determined by the Federal Emergency Management Agency, and, on July 6, 1984, it was included in the National Defense Stockpile (NDS) with an initial goal of 30,000 kilograms of germanium metal. On July 24, 1987, a new NDS goal of 146,000 kilograms was

established, based on the Army's estimates for actual emergency conditions of mobilization.

Some of the metal inventory acquisitions made the previous year were delivered in 1991, and, as of December 31, the stockpile inventory was 68,913 kilograms of germanium metal.

Production

The U.S. Bureau of Mines estimated domestic refinery production from both primary and secondary materials to be 15,000 kilograms, a decrease of about 17% compared with that of 1990. Germanium producers were forced to scale down their output to meet falling demand for the metal by the Department of Defense.

On January 7, 1991, Eagle-Picher Industries Inc. announced that some of its affiliates had filed for reorganization under chapter 11 of the U.S. Bankruptcy Code in the U.S. Bankruptcy Court for the Southern District of Ohio, Cincinnati, OH. This action was taken by the company to cope with mounting personal injury claims against it as a result of an insulation product containing asbestos that it made more than 50 years ago. However, corporation officials assured the public that all operations, including production of the specialty materials (germanium and gallium), were not impaired by this action, and the company would be able to meet all of its commitments.⁴

Consumption and Uses

The U.S. Bureau of Mines estimated that consumption of germanium decreased about 3% compared with the level of 1990 as a result of decreasing demand for the metal. The estimated consumption pattern by end use of germanium in 1991 was as follows: infrared systems, 62%; fiber optics, 14%; gamma-ray, X-ray, and infrared detectors, 7%; semiconductors (including transistors, diodes, and rectifiers), 7%; and other applications (catalysts, phosphors, metallurgy, and chemotherapy), 10%.

Infrared systems and fiber optics continued to be the major end uses for germanium. Infrared optics were mainly used for military guidance and weapon-sighting systems. Germanium-containing lenses and windows transmit thermal radiation similarly to visible light transmission by optical glass. Germanium glass was also used for nonmilitary surveillance and monitoring systems in fields such as satellite systems and fire alarms. Germanium is used as a dopant in the core of many optical fibers employed in telecommunications.

The next-generation night navigation and targeting systems for the U.S. Army's new Light Helicopter will be provided by Martin Marietta Corp., Bethesda, MD. The company's new system is the latest version of the technology originally developed by the same corporation for the Army's Apache helicopter, but it incorporates advanced infrared focal plane arrays technology to produce higher resolution, TV-like images from greater distances than present systems. The value of the contract was expected to be about \$1 billion.⁵

Markets and Prices

Throughout 1991, domestic producer prices for germanium metal and dioxide, published by Metals Week, remained at the levels established in late 1981 (\$1,060 and \$660 per kilogram, respectively). However, discounting by producers was evident during 1991 because of competition from imported materials.

Free market prices, published by Metal Bulletin (London), which in June 1990 were in the range of \$500 to \$550 per kilogram, by May of 1991 reached a low range of \$340 to \$350 per kilogram; prices remained stagnant at that level for the remainder of the year. Plenty of germanium products were available on the market, and the world's oversupply was further aggravated by the U.S.S.R.'s entrance in the marketplace as an active supplier of germanium.

The Belgian producers' price for germanium metal, published by Metal

Bulletin (London), remained throughout the year at about \$860 per kilogram.⁶

Foreign Trade

In 1991, the estimated germanium content of imports was approximately 26,000 kilograms. Total imports of germanium materials decreased dramatically compared with those of 1990. The United Kingdom, Belgium, the Federal Republic of Germany, France, Hong Kong, and Canada, in descending order of shipments, accounted for approximately 88% of the total U.S. germanium imports for 1991. (See table 2.)

World Review

World refinery production was estimated at 80,000 kilograms, a decrease of about 2% compared with the 1990 level. The decline in world production was attributed to an oversupply and to a lower level of demand for the metal.

Capacity.—The data in table 3 represent rated annual production capacity for refineries on December 31, 1991. Rated capacity was defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable, long-term operating rate, based on the physical equipment of the plant and routine operating procedures for labor, energy, materials and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditures. (See table 3.)

Refineries' rated capacity of germanium was estimated based on discussions with some officials from private industry, past and present production rates, and published capacity data.

Japan.—Germanium metal production was 3,419 kilograms, an increase of more than 1% compared with 1990 metal production levels. However, germanium

dioxide production decreased from 12,350 kilograms in 1990 to 11,493 kilograms in 1991.

United Kingdom.—STC Submarine Systems, a subsidiary of Northern Telecom of London, United Kingdom, will supply a fiber-optic cable link between Copenhagen, Denmark, and Kingisepp, near St. Petersburg in the U.S.S.R. The 1,620-kilometer cable under the Baltic Sea will cost an estimated \$65 million.⁷

Current Research

The U.S. Bureau of Mines investigated germanium and gallium extraction from an ore sample obtained from the Apex Mine near St. George, UT. The sample contained about 0.09% germanium and 0.04% gallium. Research results showed that about 87% of the germanium and 97% of the gallium content in the sample were extracted, using a two-stage countercurrent sulfuric acid leach circuit. This study also determined that more than 10% of the germanium in the ore sample was in solid solution with silica, which would be unextractable with sulfuric acid.⁸

OUTLOOK

There were abundant supplies of germanium materials on the market in 1991. Germanium supplies are likely to remain high for the next 2 to 4 years owing to an increased availability of concentrates from Canada and also to a considerable amount of germanium metal emerging into the world market from the U.S.S.R. Producers for the second consecutive year were forced to lower prices to maintain their share of the market.

Market analysts agree that all primary germanium producers will probably face difficult times in the near future. This assessment is based on a continuing global oversupply of germanium materials together with a low market demand.

⁵Weber, J. N. *Geochemistry of Germanium*. Dowden, Hutchinson & Rose Inc., Stroudsburg, PA, 1973, pp. 1-5.

²Adams, J. H. Germanium Compounds. Ch. in Encyclopedia of Chemical Technology. Kirk-Othmer, 3d ed., v. 11, 1983, pp. 791-802.

³Battelle Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallurgical Mineral Processing (Phase 6—Energy Data and Flowsheet, Low-Priority Commodities). BuMines OFR 117(1)-76, 1976, pp. 79-82; NTIS PB 261150/AS.

⁴Eagle-Picher To Reorganize Under Chapter 11. Eagle-Picher Industries, Inc. Press Release, Cincinnati, OH, Jan. 7, 1991.

⁵Photonics Spectra. Martin Marietta To Provide Night Vision for the Army's New Light Helicopter. V. 25, No. 5, May 1991, p. 8.

⁶Where necessary, values have been converted from Belgian francs (BF) to U.S. dollars at the average exchange rate of BF34.5=U.S.\$1.00.

⁷Photonics Spectra. Fiberoptics To Link Denmark and the U.S.S.R. V. 25, No. 11, Nov. 1991, pp. 40-41.

⁸Harbuck, D. D., M. D. Odekirk, and J. C. Judd. Sulfuric Acid Leaching of a Germanium Gallium Ore. SME Annual Meeting, Denver, CO, Feb. 25-28, 1991. Preprint No. 91-95; 5 pp.

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Germanium. Ch. in Mineral Commodity Summaries, annual.

Germanium. Ch. in Mineral Facts & Problems, 1985 ed.

Other Sources

American Metal Market.

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Metal Bulletin (London).

Metals Week.

Mining Journal (London).

TABLE 1
U.S. IMPORT DUTIES FOR GERMANIUM MATERIALS

Item	HTS No.	Most favored nation (MFN)	Non-MFN
		Jan. 1, 1991	Jan. 1, 1991
Germanium: Waste and scrap	8112.30.3000	Free	Free.
Germanium other: Unwrought	8112.30.6000	3.7% ad valorem	25% ad valorem.
Germanium other: Other	8112.30.9000	5.5% ad valorem	45% ad valorem.

TABLE 2
U.S. IMPORTS OF GERMANIUM MATERIALS, BY COUNTRY¹

Country	1990		1991	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Belgium	7,506	\$7,614,049	6,921	\$6,877,552
Canada	5,469	2,841,950	1,542	390,017
China	2,078	655,351	504	151,035
Denmark	—	—	630	25,598
France	21,087	12,709,770	2,449	834,227
Germany, Federal Republic of	2,992	1,088,355	2,837	1,000,977
Hong Kong	3,062	1,302,963	2,174	523,160
Israel	508	89,247	81	105,089
Italy	—	—	201	48,296
Japan	30	3,210	17	23,920
Netherlands	4	4,697	908	88,953
Singapore	16	5,000	43	7,628
Spain	1,346	243,184	500	76,035
Sweden	20	27,964	—	—
U.S.S.R.	307	121,321	375	86,278
United Kingdom	5,364	1,263,694	7,652	1,760,000
Total	49,789	27,970,755	26,834	11,998,765

¹Revised.

¹Unwrought and waste and scrap.

Source: Bureau of the Census.

TABLE 3
WORLD ANNUAL GERMANIUM
REFINERY PRODUCTION
CAPACITY, DECEMBER 31, 1991

(Thousand kilograms)

	Capacity
North America:	
Canada	10
United States	60
Total	70
Europe:	
Belgium	50
Other ¹	100
Total	150
Asia:	
China	10
Japan	35
Total	45
World total	265

¹Includes estimates for former U.S.S.R.

GOLD

By John M. Lucas

Mr. Lucas, a geologist with more than 30 years of experience in the mining industry, has been the U.S. Bureau of Mines commodity specialist for gold since 1980. While with private industry, Mr. Lucas was involved in exploring for a wide variety of commodities, including gold, in the United States as well as in Australia, Brazil, and Canada. Domestic survey data were prepared by Dwayne E. Penn, Lisa P. Conley, mineral data assistants, and Stephen L. Hays, supervisory mineral data technician. International data tables were prepared by Audrey D. Wilkes, international data coordinator.

Throughout history, gold has been treasured for its beauty and permanence. Most of the gold that is fabricated today goes into the manufacture of jewelry. However, because of its superior electrical conductivity and resistance to corrosion and other desirable combinations of physical and chemical properties, gold also emerged in the late 20th century as an essential industrial metal. Gold performs critical functions in computers, communication equipment, spacecraft, jet aircraft engines, and a host of other products. Although gold is important to industry and the arts, it also retains a unique status among all commodities as a long-term store of value. It was, until recent times, considered essentially a monetary metal, and most of the bullion produced each year went into the vaults of government treasuries or central banks.

Domestic and international gold mining operations continued to produce gold at a record level during 1991. The U.S. gold mining industry produced 289,885 kilograms (kg) (9,320,006 troy ounces¹) of gold, essentially the same as that of the previous year. The State of Nevada was once again the Nation's dominant gold-producing State. For the third consecutive year the total demand for gold used in fabricated products in the market economy countries exceeded the record demand level set in 1988. Jewelry continued to be the dominant end-use sector.

The U.S. Bureau of Mines, in an effort to provide statistical data on gold that are consistent with international

usage, reports gold data in kilograms and metric tons unless otherwise noted.

DOMESTIC DATA COVERAGE

Domestic mine production data for gold are developed by the U.S. Bureau of Mines from two separate, voluntary surveys of U.S. operations. One of these surveys is the lode-mine production survey of copper, gold, lead, silver, and zinc mines. Of the lode gold producers in operation to which a survey request was sent, 211 responded, representing 98% of the total lode-mine production of gold shown in tables 4 and 5. Production for the nonrespondents was estimated using reported prior-year production levels, adjusted by trends in employment, and other guidelines such as company annual reports, the news media, and State agency reports.

BACKGROUND

Gold lore and the use of gold predates written history. Gold has been considered a precious metal since ancient times, and the mystique and folklore associated with gold has been a part of the fabric of civilized society throughout history. Similarly, the search for gold has stimulated world exploration and trade for more than sixty centuries.

Gold mining in the United States began about 1800 in North Carolina, with Georgia joining in production in 1829 and Alabama in 1830; then Virginia, Tennessee, and later New Mexico became producers as prospectors moved west.

The most important gold discovery, because of its influence on development in the Western United States and the amount of gold produced, was at Sutter's Mill in California in 1848. Later discoveries were made in most other Western States and territories.

Gold mining in Australia began about 1849 as an offshoot of the California gold rush. Russian gold mining had been expanding since the mid-18th century, and by the eve of the California gold rush, Russia was producing about two-thirds of the world's gold. Gold mining in the Republic of South Africa started in the 1870's. The last major gold rush began just prior to 1900 in Canada's Yukon and in Alaska.

Early mining was largely by placer methods, with a multitude of miners working stream deposits (placers) by hand mining techniques, a practice that continues to this day in many areas of the world. In the 1860's, the more difficult underground mining of lode deposits—the sources of the placers—became important. Cyanidation, a chemical process for gold extraction, was introduced about 1890, and the concentration of finely ground ores by selective adherence of mineral particles to rising bubbles, the flotation process, was first used for gold ores about 1900 and came into general use in the 1930's. Heap leaching, essentially a form of cyanidation, has come into general practice for treatment of low-grade ores only during the past 2 decades.

Cumulative world production to date is estimated at more than 109,000 tons (3.5

billion ounces), about two-thirds of it mined in the past 60 years. The total is equivalent in volume to a cube roughly 18 meters (58 feet) on a side. The Republic of South Africa has been the source of about 41% of that gold, but nearly all countries have reported at least some production of gold.

U.S. gold production, from its beginning in the 18th century to date, totals about 11,600 tons (372 million ounces). The principal producing States, in declining order of cumulative production, are California, Nevada, Colorado, South Dakota, Alaska, Utah, and Montana; the remainder came from 11 other States. To date, lode gold mining has supplied about 50% of U.S. production; placer mining, 35%; and base metal mining, 15%. The Homestake Mine at Lead, SD, has accounted for about 10% of all U.S. gold production. Other major sources of past production include the Mother Lode and Grass Valley areas of California, the Comstock Lode and Goldfield areas in Nevada, Cripple Creek in Colorado, and the Fairbanks and Nome, AK, areas.

Most domestic gold mines were closed by Limitation Order L-208 in the early months of World War II (October 8, 1942) so that scarce equipment, supplies, and skilled workers could be focused on mining essential base metals. L-208 was revoked July 1, 1945. Because of increased cost and rehabilitation problems, only a few mines reopened after the war. During the resurgence of gold exploration and mining over the past decade, many deposits affected by L-208 have been reexamined or returned to productive status.

Definitions, Grades, and Specifications

Fineness refers to the weight proportion of pure gold in an alloy, expressed in parts per thousand; 1,000 fine gold is 100% pure gold. Commercially traded gold bullion is usually 995 fine or higher. The term "fine gold" may also be used to designate the particle size of gold in its native state; for example, a placer deposit with gold particles ranging from 0.38 millimeter

(mm) to 0.76 mm (0.015 to 0.3 inch) in diameter contains fine gold, whereas a similar deposit with particles more than 1.5 mm (0.06 inch) in diameter contains coarse gold.

The term "karat," like fineness, refers to purity, but is expressed in 24ths; thus 24-karat (24k) gold is 1,000 fine or pure gold, and 10k gold is 10/24, or 41.7% gold. Although there are many 10k alloys, each 10k alloy contains 41.7% gold. Various 10k alloys, for example, differ from each other in the number, identity, and proportions of their other constituent metals. Gold alloys used in jewelry and certain other end uses are referred to as karat golds, whereas alloys used in dentistry and electrical devices are designated more precisely. Yellow, red, and green karat golds are essentially ternary alloys of copper, gold, and silver, often with additions of zinc and sometimes a little nickel. White karat golds are usually composed of copper, gold, nickel, and zinc, although platinum and palladium have also been used as components.

Having assumed the functions previously performed by the London Gold Market, the London Bullion Market Association (LBMA), established in 1987, sets standards for its members that are widely used in world gold trade. Refined gold bullion bars are generally designated as "good delivery bars." A good delivery bar, as set forth by the requirements of the LBMA, must contain 350 to 430 troy ounces of gold with a minimum fineness of 995. The bar must bear the stamp of one of the world's 49 approved smelters or assayers, have a good appearance, and be easy to handle and stack. Smaller bars are also commonly available on the commercial gold market.

U.S. trade practice rules for the jewelry industry, set by the Federal Trade Commission, require that any article labeled gold must contain at least 10k gold, with a tolerance of three parts per thousand for most articles, or if soldered, seven parts per thousand. "Rolled gold plate" and "gold filled" are terms referring to articles made of base metal to which karat gold has been bonded by soldering, brazing, welding, or

mechanical means. A marking such as "1/10 10-karat gold filled" means that one or more surfaces are covered with 10-karat gold and the coating constitutes at least 10% of the weight of the entire article covered. No article may be marked "gold filled" if its karat gold surface constitutes less than 1/20 of the total weight. Thinner coatings are marked "rolled gold plate."

Gold has an atomic number of 79 and an atomic weight of 197, occurring naturally as a single stable isotope. The melting point of gold is 1,063° C. Gold's specific gravity is 19.3; it is about seven times heavier than an equal volume of metallic aluminum. In addition to being highly resistant to corrosion, gold is also extremely malleable and ductile; 31 grams (1 troy ounce) can be beaten into about 250 square feet of gold leaf about four-millionths of an inch thick, while a similar quantity can be drawn into more than 80 kilometers (km) (50 miles) of wire.

As an illustration of gold's high specific gravity or density, 1 cubic foot of pure metallic gold weighs a little more than 1,200 pounds; one cubic inch of pure gold weighs about 311 grams (10 troy ounces); a lump or nugget of gold the size of a navy bean weighs about 3 grams (0.1 troy ounce), and a flake of gold the size of a grain of rice weighs about 0.18 gram (0.006 troy ounce).

The troy system of weights is generally used in the United States for gold and other precious metals; however, to aid in harmonizing world data collection, Government practice now dictates the use of the metric system of measure. The troy weight system is based on the troy ounce of 480 grains or 20 pennyweight. One troy ounce is equivalent to 1.097 ounces avoirdupois. Many nations use the metric system; in this system, the weight of gold is designated in standard metric units: gram, kilogram, or metric ton. The metric ton is equivalent to 32,150.7 troy ounces. In addition to the metric or troy systems, other units of weight applicable to precious metals may also be encountered. On the Indian subcontinent, for example, the weight of gold may be expressed in terms of tolas;

one tola of 999 fine gold weighs 11.1 grams (0.375 troy ounce).

Uses and Products for Trade and Industry

In addition to its ages-old usage as a monetary metal as well as in jewelry, decorative applications, and dentistry, gold has a number of applications that are important to the functioning of domestic industry, modern high-technology, engineering, and defense systems. It is used extensively in a great variety of solid-state electronic devices, in industrial control and monitoring instruments, and in corrosion-resistant chemical process equipment.

Of the strategic and industrial uses of gold, the most important is its use in electronic devices, especially in printed circuit boards, connectors, keyboard contacts, miniaturized circuitry, and as a dopant in some semiconductors. Modern solid-state electronic devices such as computers employ very low voltages and currents, and thus require connectors, switch contacts, soldered joints, and certain other components that remain chemically and metallurgically stable for the life of the device. Increasingly complex civilian, military, and aerospace electronic systems use gold to ensure dependable operations under a wide range of operating conditions. For example, because of its ability to provide reliable electrical connections, gold is used extensively in spacecraft such as the *Hubble Space Telescope* that must function flawlessly in the harsh environment of outer space. A more down-to-earth example would be the common touchtone telephone that has up to 33 gold contact points; gold plating employed on the contact surfaces of the quick disconnect between the telephone and the line ensures static-free reception.

Gold alloys have long been used in certain electrical instruments; for example, as wipers and windings in slide-wire potentiometers, where long-term reproducibility is essential. Gold-palladium alloy wires are used in thermocouples, especially those used to measure high temperatures encountered in

some industrial processes and aircraft engines. Gold-containing brazing alloys such as gold-nickel alloy are important to the aerospace industry, especially in the assembly of some military jet turbine engines and high-performance rocket engines. Gold is used as a reflector of infrared radiation in radiant heating and drying devices and heat-insulating windows for large buildings. It is used in spacecraft such as the space shuttle, which relies upon gold to seal and protect its vital propulsion system from problems associated with hydrogen embrittlement. Gold-coated mirrors are the principal component of infrared jammers used on numerous military aircraft to confuse the guidance instruments of heat-seeking missiles.

Gold applied as organometallic liquids is used for the decoration of porcelain and glass dinnerware; gold leaf is used for the decoration of buildings, both inside and outside; and gold alloys are used in rupture discs in chemical process equipment and in the perforated "spinnerets" through which cellulose acetate fibers are extruded. Since 1975, when Americans could again hold gold without a license, a small amount of gold has been used in the United States each year for medallions, small bars, and other similar items having high gold content, purchased primarily as investments.

Although gold compounds are used in substantial quantities in electroplating, most of the gold sold in the international marketplace for industrial usage is in the form of metal or metal alloys. Many standard metallic forms are available, such as bars, rods, sheets, foils, wires, powder, granules, and shot. Conductive pastes and inks prepared with gold powder are widely employed in the electronics industry. Much jewelry gold is supplied as granules of specified karat content. Semimanufactured items for trade and industry may include gold jewelry findings or unassembled parts such as earring clamps, chain clasps, pins, etc.; dental findings; and inlaid, clad, and plated metals. Investment products such as bars, coins, and medallions are manufactured and sold by both industry and governments.

Industry Structure

In the United States during 1991, 90% of domestic gold production came from gold ore, and most of the remainder was a byproduct of copper and other base metal production. Placer gold production has declined to about 1% of the reported total production in recent years. Fifteen mines accounted for about 60% of domestic output in 1991; 83% came from mines in California, Montana, Nevada, and South Dakota. The leading producer in most recent years, Newmont Gold Co., provided about 17% of domestic output from its surface operations near Carlin, NV. The Homestake Mine, a deep underground mine in South Dakota, has been a major producer for many years. The Utah Copper Div. of Kennecott, a major copper producer, has been a significant gold producer in many years since 1979, a year when it was the Nation's largest gold producer. Kennecott's gold is a byproduct of its extensive copper mining operations at Bingham Canyon, UT.

Attracted by the favorable U.S. business climate, foreign investment in domestic firms that produce gold as a principal product or as a byproduct has increased since 1980. This is especially true for mining interests acquired by multinational companies, some of which in turn may be directly linked to foreign governments. The general attractiveness of the United States as a country in which to conduct business has been a principal motive behind these acquisitions. Canadian mining companies have, throughout the history of North American mining, operated mines in the United States, as to a lesser extent have United Kingdom and other European companies.

The South African gold mining industry, accounting for about 27% of current world output, consists of about 3 dozen large underground operations and several dozen smaller mines. In a typical year, the Republic of South Africa's gold industry reportedly mills enough ore to cover 60 city blocks to a height of 20 stories; from this volume is recovered enough gold to fill a small bathroom. These mines are owned or controlled by

six corporations that interlock through directorships and mutual shareholdings and have extensive mineral and industrial investments in many parts of the world. The corporations are Anglo American Corp. of South Africa, Ltd.; Anglovaal Ltd.; Gencor Ltd.; Gold Fields of South Africa, Ltd.; Johannesburg Consolidated Investment Co. Ltd.; and Rand Mines Ltd.

Geology-Resources

The Earth's crust has been estimated to have an average gold content of about 0.0034 gram per metric ton (0.0001 ounce per short ton), or 3.5 parts per billion (ppb). Sedimentary rocks, especially sandstones, tend toward higher-than-average gold content. In igneous rocks, the content averages slightly higher in darkly colored "mafic" rocks than in lighter colored "felsic" rocks. Seawater typically contains about 0.011 ppb gold; however, content varies widely with location and may range from 0.001 to 44 ppb. Numerous attempts have been made over the years to recover gold from seawater; however, none have been commercially sustainable. The gold content in surface and ground waters lies within the range of analyses for seawater, but varies widely depending on source. For instance, waters from gold mines in southern Yakut, U.S.S.R., contain an average of 0.7 to 0.9 ppb. In Colorado, waters draining from gold mining and other areas contain up to 0.15 ppb, but with no distinct differences between gold-enriched and gold-barren areas. Hot-spring waters generally contain more gold than other waters.

Gold deposits are found in many kinds of rock. Hydrothermal deposits appear to be somewhat more common in acidic and intermediate igneous rocks; in silty, laminated carbonate rocks; and in silicious or aluminous sedimentary or metamorphic rocks. The general deposit types include hydrothermal, hydrothermal-metamorphic, metamorphic, replacement (lode, massive, and disseminated), and cavity filling (fissures, stockworks, saddle, reefs, breccias, and conglomerates).

Gold occurs mainly as native metal, alloyed with silver and/or other metals, and as tellurides. A naturally occurring alloy of gold and silver is known as electrum. Other gold minerals are rare. Gold is commonly associated with the sulfides of antimony, arsenic, copper, iron, and silver.

Chemical and mechanical weathering and erosion cause gold in the free or metallic form to be released from lode or primary deposits and to accumulate as nuggets and grains in residual deposits or placer deposits. Although the richest lode gold deposits have been small fissure vein types with quartz gangue, the so-called bonanzas, much larger quantities of gold have been mined from large, medium-grade deposits. U.S. gold ores average about 3.5 grams per metric ton (0.1 ounce per short ton) or less; however, the advent of chemical heap leaching now makes it possible for rock with suitable properties containing considerably less than 3.5 grams per metric ton to be considered ore.

Technology

Exploration.—Although a number of new techniques have come into use in the exploration for gold, the gold pan remains one of the simplest and most efficient low-cost means of finding visible gold and tracing it to its source. Collecting, crushing, and panning quartz samples from geologically favorable areas is a common basic procedure employed in prospecting for bonanza-type lode deposits. Neutron activation analysis and atomic absorption spectroscopy, when properly applied, permit relatively fast and reliable gold analyses and have had an important bearing on the ability of field geologists to do geochemical surveys of areas formerly of little interest because of sampling costs and lack of outcrops. The long-established fire assaying technique, however, continues to be the most widely used method for determining the quantity of gold present in samples or market products where precision and accuracy of the results are important. The thoroughness of the fire assay method, however, usually results in overvaluation

when applied to placer samples. Even the most efficient placer gold recovery technique cannot always recover all of the gold values detected by fire assaying; recovery of the available free gold by panning and amalgamation generally yields more representative results. Newmont Gold Co. recently initiated an automatic assay system whereby more than 4,900 laser-read barcoded samples are directed daily through the various laboratory stages with the aid of computers. Geochemical studies have established relationships between gold and other elements, such as arsenic, copper, mercury, and tellurium, which can be useful trace elements in the search for gold. In recent years, computers have proven to be useful in determining the often subtle relationships between trace elements and gold mineralization. Metallogenic studies relating tectonic histories and regional and local geology have given better understanding of where important gold deposits may lie.

Wire-line core drilling and improved percussion drilling methods have reduced the costs and increased efficiencies of exploration and development. Research on sampling through statistical analysis techniques that take into account the distribution and size of gold particles in a sample has shown ways to effectively reduce sampling costs. Computer methods have been useful in defining the extent of pay zones in larger ore bodies, such as those in the Republic of South Africa, and have application to low-grade disseminated deposits. Improvements in mining machinery and procedures and the introduction of new gold leaching methods have combined to lower the economic cutoff limits for gold deposits, providing an impetus for extensive reevaluation of previously mined areas as well as the incentives necessary to encourage the exploration of new, heretofore unproductive, areas.

Mining.—The technology of gold mining is well established, having evolved largely over the past century. Much of the world's gold production has come from deep, narrow veins or from thin-bedded layers called reefs; these

have been difficult to mine (in the Republic South Africa, for example) because of high underground temperature and humidity and extreme rock pressure, which often cause dangerous rock bursts. Most domestic gold comes from surface lode mines.

Placer mining was once an important source of gold. Dredging offers the maximum efficiency in large alluvial or marine deposits; dragline, hydraulic, or bulldozing methods are commonly used in smaller, bouldery deposits such as those mined in some areas of Alaska. Most placer mining requires large quantities of water, but dry operation is also possible using bellows or other air-blowing equipment for separation. However, recovery efficiency may be lower in dry processing. To illustrate the effort entailed in small-scale manual placer mining, such as that which has been and continues to be practiced in many areas of the world, including the United States, two persons feeding a sluice box can shovel about 6 cubic yards of gravel per day. This is roughly equivalent to loading the beds of six 1-ton pickup trucks per day. Assuming that the gravel processed yields an average 0.49 gram per cubic meter (0.01 ounce per cubic yard) of gold, about 3 grams (0.06 ounce) of gold would be recovered per day. With a gold price between \$350 and \$400 per ounce, the gold recovered by two persons laboring all day would have an approximate value of \$21.00 to \$24.00, hardly an acceptable wage in the United States but a substantial sum in many areas of the world. Obviously, mechanization, even on a small scale, would vastly increase the amount of material that could be washed. Needless to say, mining a higher grade deposit would be even more productive. Should the gold recovered be in the form of coarse nuggets, valued also for their use in jewelry or as specimens, the value of the day's production would be increased. For large-scale, open pit lode gold mining, computer models have been developed to analyze various production factors and establish optimum pit configurations and extraction efficiencies.

The South African mining industry, a leader in deep mining technology for many years, has evolved new methods of controlling problems relating to rock stress, dust, and virgin rock temperature. Both large and small water-powered rock drills, large-diameter raiseboring machines, and new types of rubber-tired transporters have been developed in recent years to increase the efficiency of mining operations. Also, the South Africans have developed new techniques of shaft sinking, mineral processing, and extraction that are critical to the success of deep mining. At the Vaal Reefs Mine, for example, part of the gold ore is transported to the surface from a depth of more than 2,100 meters (7,000 feet) by hydraulic pumps. Much of the Republic of South Africa's current production is now coming from depths of 2,000 to 3,000 meters (6,600 to 9,800 feet) below surface, with some as deep as 3,600 meters (11,800 feet). The new generation of ultradeep mines are intended eventually to be mined to 4,500 meters (14,800 feet).²

Beneficiation.—Milling technology for gold is highly developed, and normal mill recovery rates range from 92% to 96%. Gold is recovered by cyanide leaching of gold ore contained in tanks or heaped on impervious leaching pads; by amalgamation, flotation, gravity concentration, and smelting; or by a combination of these processes. Increased exploitation of gold-bearing sulfide ores in recent years has led to the development and application of several technologies designed to render sulfide and refractory ores amenable to cyanide leaching; thus, process steps such as autoclaving, biological preoxidation, or fluid-bed roasting have recently been incorporated at a number of milling operations.

Smelting-Refining.—Many gold mining operations recover the gold from cyanide leach solutions by precipitation with zinc dust, though, in recent years, carbon-in-pulp (CIP) recovery technology has been adopted at a number of new mining operations. With CIP, activated

carbon made from coconut shells or other durable carbon sources collects gold from the cyanided pulp until it contains 10 to 12 kg (300 to 400 ounces) of gold per ton of carbon. Gold with accompanying silver is desorbed or stripped from the carbon with a strong alkaline cyanide-alcohol solution. The precious metals are recovered from the strip solutions by electrodeposition on a stainless steel wool cathode. The cathode deposit is then refined into bullion or doré, a mixture of mostly gold and silver. The carbon is reused after being screen-sized and reactivated through controlled roasting. Generally, gold recoveries range from 92% to 97% of the feed content. Gold leaching processes in use or under development that do not employ cyanide as the principal lixiviant or dissolution medium include the application of thiourea, iodine, malonitrile, or various bioextraction techniques. Some of these alternate techniques, unlike the long-established, well-understood cyanide process, may be accompanied by unacceptable cost or environmental burdens. When gold is associated with copper ores, it travels with the base metal through concentration and smelting to the refining stage. It is eventually separated from the anode slimes that accumulate in electrolytic copper refining cells and is recovered as gold bullion in the precious metals refinery. Gold losses in concentrating copper ores are about the same as for copper, but are negligible in smelting and refining.

Gold is refined by chlorination in the molten state (Miller process) and by electrolysis (Wohlwill process). Generally, gold bullion made by the Miller process is 996 to 997 fine, and bullion made by the Wohlwill process is 999.5 to 999.8 fine. (See figures 1 and 2.)

Recycling.—Because of its high intrinsic value, gold has been recycled throughout the ages. Thus, a modern article of jewelry containing recycled gold could conceivably contain atoms of gold from a golden earring worn by Helen of Troy or from a nugget of gold used in the year 4000 B.C. to barter for ingots of

crude copper or other goods at a Mediterranean seaport.

Precious-metals refiners throughout the world recover gold from scrap. In the United States, about 60% to 80% of the scrap comes from current manufacturing operations, and the remainder comes from old scrap in the form of items such as discarded jewelry and dental materials, used plating solutions, junked electronic equipment, etc. Gold is so valuable that even the gloves, aprons, and dust masks worn by gold workers and the dust or "sweeps" from their shops may be processed to yield payable quantities of metal. Similarly, a specialized field of secondary gold recovery focuses on gleaning gold from defunct gold-processing operations. Most domestic scrap processors are in the northeastern States.

The general flow of gold in the secondary industry is shown in figure 3. Refiners receive scrap in a variety of forms and determine processing steps according to batch size, average gold content, and the impurities to be separated. Scrap dealers and semirefiners may process the scrap and then ship the upgraded product elsewhere, including overseas, for further treatment and refining. Scrap is either purchased outright or treated on a toll basis.

A considerable quantity of scrap is generated in manufacturing operations, but because of tight security controls over waste materials in precious-metals plants, nearly all of this new scrap or "home-generated" scrap is recovered. Some old scrap, on the other hand, is lost because in practice gold cannot be economically recovered from all manufactured products; this is increasingly true as miniaturization of gold-bearing electronic products proceeds. The U.S. Department of Defense recovers a significant quantity of gold from military scrap; other Federal Government agencies either participate in the Defense recovery program or have their own. (See figure 3.)

Economic Factors

On January 31, 1934, following provisions of the Gold Reserve Act of that year, the official price of gold was raised by the U.S. Government from \$20.67 per ounce to \$35 per ounce. The value of \$1 was thus established at 28.57 thousandths of a troy ounce, and gold flowed into the United States. By 1949, gold stocks held by the U.S. Department of the Treasury had risen to a peak of 21,708 tons (698 million ounces).

During the 1950's and 1960's, foreign central banks vigorously exchanged their large dollar holdings for U.S. gold. Consequently, U.S. stocks declined, with much of the gold accumulating in stocks owned by foreign governments. When the outflow of gold was finally stemmed in August 1971 by a Presidential order closing the so-called "gold window" or ending the convertibility of U.S. dollars into gold, U.S. stocks stood at 9,069 tons (291.6 million ounces). Thereafter, U.S. stocks declined somewhat, reflecting gold auctioned by the Department of the Treasury in 1975, 1978, and 1979 and later minting of gold coins and medallions for public sale. At yearend 1991, U.S. Treasury stocks stood at 8,146 tons (262 million ounces).

Because of increasingly severe pressures on official gold reserves stemming from attempts by monetary agencies to hold the price of gold down to \$35 per ounce, a seven-nation International Gold Pool established a two-tier price system in March 1968. Under this system, there was an official price of \$35 on monetary transactions, thenceforth restricted to Government-owned gold, and an open market price for other transactions, which could fluctuate with supply and demand. Since then, the free market has flourished, and the price of gold has risen dramatically, while the monetary sector has evolved to the point where most nations conduct gold transactions and value their gold reserves at market-related prices. The United States is the only remaining holder of large gold reserves to value them at the low official price of \$42.22 per ounce. The U.S. dollar was devalued twice in

the 1970's, raising the dollar price of gold to \$38 per ounce on May 8, 1972, and then to \$42.22 on October 18, 1973, where it remains today. With the second devaluation, the President was empowered to eliminate regulations on the private ownership of gold, which had been in force since 1934, and these were eventually removed on December 31, 1974. January 2, 1975, was the first day that the general public was allowed to resume holding gold without a licence issued by the U.S. Treasury's Office of Domestic Gold and Silver Operations; the office was closed on July 31, 1975.

Trading in gold futures began in New York and Chicago upon restitution of the right to private ownership of gold. Trading volume has increased nearly sixteenfold since 1975, peaking at about 43,000 tons (1,380 million ounces) in 1982; the volume in subsequent years has ranged from about 25,000 to about 35,000 tons. However, only a small percentage of the gold traded enters the physical market.

Because of gold's monetary role and the fixed \$35-per-ounce price from 1934 to 1968, domestic producers had difficulty maintaining production in the face of rising costs. Gold was particularly attractive as a commercial metal because its price was stable, and a dependable domestic supply was provided to industrial users by the U.S. Treasury until March 17, 1968.

In March 1982, the U.S. Gold Commission, which had earlier convened to consider a renewed role for gold in the U.S. economy, concluded that reintroduction of gold into the current monetary system would probably not serve to alleviate potential economic problems such as inflation. The prospects for a return to a gold standard in other countries would also seem to be uncertain. However, as a so-called "hard currency," gold may come to enjoy a greater role in world economics than it has in the recent past. This is especially important as the world economic system adjusts to accommodate rapidly changing political, economic, and trade practices and to address the many issues associated with the rapid growth in world

population, dwindling resources, and slower growth in industrial productivity. Small-scale bartering arrangements involving gold continue as they have for centuries, especially in frontier mining areas such as those in South America, Africa, the western Pacific, and remote areas of North America where raw gold dust and nuggets may be used directly to purchase goods and services.

Prices.—The price of gold is a topic of continuing concern and interest to the producer and the consumer of gold alike; where it has been, where it will go, and the reasons behind its wild fluctuations over the past decade or so have been studied from every angle by numerous observers. Apparent causes for the price changes have been presented, and speculation on their future directions have been offered.

Unfortunately, many of these sophisticated econometric models, forecasting the price using combinations of economic, political, and social factors, that proliferated in the early 1980's had all but disappeared from the public domain by the end of the decade. The course of future events cannot, of course, be forecast with accuracy, nor can the price of gold. Forecasting gold's price is unusually complicated because gold occupies a unique position among the world's commodities. Gold is both an internationally traded commodity and, at the same time, a long-established, universally acceptable storehouse of value, considered by many people worldwide to be superior to fiat paper currencies with fleeting longevity or fluctuating, unpredictable value. Unlike many commodity prices that are more or less tied directly to supply and industrial demand, the price of gold cannot be viewed as one would view the price of other goods or services in a free market. Gold also cannot be viewed strictly from the standpoint of the U.S. market alone, for international, political, and economic events that may impose a positive or negative influence on gold the commodity may be overshadowed by developments perceived to favor gold the medium of exchange. For example, citizens of

nations that have been invaded by other countries during the course of their history tend to value the monetary and exchange aspects of gold more highly than countries such as the United States where this has not been the case. To them, gold is money or the preferred substance of wealth, and the ownership of even a small amount of physical metal ensures escape or a new beginning. Therefore, many individuals worldwide, as a matter of tradition or simple prudence, continue to hold small quantities of gold in the form of jewelry, coins, nuggets, etc., legally or illegally, as a portable form of universally accepted capital; for some, especially in developing countries, gold may constitute the only available and relatively risk-free form of old age or disaster insurance.

Although the average price of gold has declined from its record 1980 level of \$612 per ounce, it remains considerably higher than the prices of the early 1970's. This high price level, not generally enjoyed in recent years by many other commodities, continues, albeit to a lesser extent today than during the mid-1980's, to spark investor interest and lead to an overall sustained increase in the level of funding available to gold producers to invest in exploration and productive capacity. The heightened interest in gold has, as in the past, promoted exploration of those remote corners of the Earth where exploration for other less valuable minerals could not be justified but where their serendipitous discovery as a byproduct of exploration for gold will ultimately contribute to the needs of society.

In the fabrication of gold, particularly in the electronic and electrical industries, the cost of gold used per unit item is still such a small percentage of the total unit cost that the price of gold is often of small significance in pricing the product. Some industrial consumers of gold, however, confronted with unpredictable and potentially ruinous prices, have turned in recent years to the world futures markets to ensure that their future gold requirements will be available at preselected prices.

Costs.—Costs of mining gold in the United States range upward from costs typical of low-cost placer mining, where dredging or hydraulic operations are conducted profitably on gravels containing less than 0.49 gram per cubic meter (0.01 ounce of gold per cubic yard). Surface lode mining, although considerably more expensive than placer mining, is profitable with some ores containing as little as 0.2 gram or less of gold per metric ton (.006 ounce per ton), depending on the stripping ratio, size, and type of operation. Other important considerations include the characteristics of the ore processed and the mine's location with respect to the duration of the operational season and the infrastructural requirements. Underground mining for gold is the most expensive mining, but costs vary greatly from mine to mine; nevertheless, some underground mines are able to produce an ounce of gold at costs below those of some surface operations.

Costs for processing gold ores can vary widely, depending on the treatment required. Recent advances in heap leaching of gold and extraction with activated carbon may afford lower capital and operating costs than those associated with conventional cyanidation. One recent advance, for example, is particle agglomeration, a technique developed and patented by the U.S. Bureau of Mines to increase the flow rate of leaching solutions through crushed ore. Fine particles of ore that would otherwise impede solution flow by blocking the spaces between coarser fragments are bound together or agglomerated through the addition of a water-soluble binder such as portland cement or lime. Other innovative techniques developed in recent years to improve the efficiency of the heap-leaching process include the use of ore conveyors and stackers, solution heaters, and improved solution distribution and recovery and leak detection systems. Other advantages of heap leaching over conventional milling include shorter plant construction time and greater adaptability to lower grade ores. A disadvantage of conventional heap leaching is lowered recovery,

usually 60% to 80% of the gold present, compared with 88% to 92% or greater recovered by conventional mill treatment. The recovery efficiency of heap-leaching operations where agglomeration technology is employed approaches that of conventional methods.

Some producers, by forward selling of their future gold production, are able to maintain economic production even during periods when their production costs may exceed the existing market price of gold.

Taxes.—Taxes may be levied on mining operations for gold and other minerals at the Federal, State, and local levels. In addition to the usual business, occupation, and property taxes and licence fees required of all business enterprises, mining operations in many States are subject to severance or extraction taxes imposed on the yield or proceeds received from the sale of newly mined products. In 1989, the State of Nevada, for example, increased the net profits tax on State mineral production from about 2% to 5%. In 1986, a new Federal tax, the Customs User Fee, was adopted; it places a 0.22% levy on all imports, including gold and gold-bearing products. The fee was reduced to 0.17% on September 30, 1987. During 1990, the enabling legislation was extended to September 30, 1995, but in late 1991, the percentage levy was changed to a flat transaction fee of \$400 per shipment.

Most major gold-producing nations impose taxes on domestic mining operations; taxation of the gold mining industry in some countries may be specifically tailored to accommodate a nation's stated economic and political objectives. For example, in the Republic of South Africa, gold mines are taxed in accordance with two basic formulas: one taxes the profits of mines opened before 1966, while the other formula applies to newer mines. Many major gold-producing nations have also provided tax concessions, subsidies, and other assistance to gold mining. The former U.S.S.R. supported gold mining through administrative fiat. China encourages gold prospecting by both the civilian and

military population. Australian mining companies have for decades been exempted from paying taxes on profits derived from gold mining. However, effective January 1, 1991, the Government of Australia eliminated its 6-decade-old tax exemption of income derived from gold production, including byproduct production from those copper operations where gold represents more than 40% of the total income.

Operating Factors

Environmental Requirements.—The costs associated with meeting various Federal, State, and local environmental requirements can vary considerably from one mine site to another. At mines utilizing cyanide recovery techniques in their milling or heap-leaching plants, special precautions, monitoring and leak detection procedures, and site design features are employed to avoid contamination of the surrounding environment and to reduce the exposure of wildlife to cyanide-laden process streams. For example, at the Mesquite Mine in California, two solution ponds with about 4 hectares (9 acres) of exposed area have been completely covered with plastic to minimize wildlife exposure as well as water loss to evaporation. A variety of processes have been developed in recent years to detoxify or neutralize spent ore prior to disposal or final site reclamation. New regulations pertaining to cyanide use on Federal lands were issued during 1990 and further clarified during 1991 (See Legislation and Government Programs). In an emergency, chemical breakdown of cyanide can be induced quickly with chlorine gas.

Because of the danger of mercury pollution, the use of mercury amalgamation in domestic gold operations is now virtually nonexistent. Despite Government efforts to control the use of mercury, the amalgamation process continues to be used in an environmentally detrimental manner in some unregulated frontier mining operations in the Amazon Basin and in the Philippines. Mercury and arsenic can

be natural contaminants of gold ores, requiring troublesome or costly extraction processes. Other potential pollutants that may be byproducts from gold mining include antimony, bismuth, tellurium, and thallium. Two iron sulfides, pyrite and pyrrhotite, commonly occur in gold deposits and can be a source of stream pollution as they oxidize to sulfates and other soluble compounds. Pollution resulting from some placer operations may be reduced or eliminated through the use of properly designed settling ponds. Waste dumps, mill tailings, and excavations are increasingly subject to public scrutiny, and environment control costs must be taken into account along with other operating factors. Expanded mine safety requirements in recent years are another important cost factor.

Employment.—According to annual data prepared by the U.S. Department of Labor, employment in the Nation's gold mines and mills, exclusive of office employees, nearly tripled from about 7,000 in 1985 to almost 20,000 in 1990 and 1991. The number of jobs available in both surface and underground mines and associated processing plants is not always directly proportional to mine production, reflecting instead variations in development activity, the price of gold, weather, type of mining operation, etc. During 1989, citing employment studies for mining in Nevada and South Dakota, the Economics Institute of Boulder, CO,³ derived an employment multiplier of 19.4 jobs per \$1 million of gold production, giving an estimate for total direct, plus indirect employment attributable to domestic gold production, of about 51,000 persons. A companion study covering the period 1979-90⁴ showed employment multipliers and the industry's contribution to gross State products and State personal income for 11 gold-producing States. The report noted that induced employment from precious-metals production in Nevada, for example, accounted for between 14% and 20% of all new jobs created in Nevada from 1986 to 1989. An average employment multiplier of 20.3 jobs per

\$1 million in output was calculated for the 11-State area.

ANNUAL REVIEW

Legislation and Government Programs

On July 10, the President lifted economic sanctions against the Republic of South Africa, thereby allowing the resumption of imports and sales of gold Krugerrand coins and other products such as uranium, coal, and iron in the United States.

The director of the U.S. Bureau of Land Management (BLM) announced on August 14, 1990, that BLM had revised its existing bonding policies for surface mines and mines using cyanide and other leaching agents on Federal lands administered by the agency. According to the new bonding policies, mine operators had to post bonds to cover reclamation costs attributed to exploration and mining. The ceiling amounts for the bonds were about \$2,500 per hectare (\$1,000 per acre) for exploration and about \$4,900 per hectare (\$2,000 per acre) for mining operations. Operators having State bonds that met or exceeded the new reclamation requirements were not required to post a Federal bond. Mines using cyanide or other leaching agents were required to post a bond equal to 100% of BLM's estimate of reclamation costs required by Federal or State regulations. The affected areas included leach heaps, pads or dumps, or those parts of an operation discharging cyanide-bearing tailings and fluids to impoundments or ponds. Facilities not included were various forms of vat leaching, metal recovery, and refining. The new policy immediately affected new mining operations. Existing cyanide operations were to comply within 6 months and any other operations by January 1, 1992. On October 4, 1991, BLM modified its bonding policy to include previously excluded vat leaching facilities and to provide clarification of its 100% bonding requirement outlined above. Five days later, BLM issued clarification regarding the need to ensure adequate training for BLM personnel

involved in inspection of cyanide operations.

Regulations implementing the ban on the importation of gold coins minted or offered for sale in the U.S.S.R. were repealed by legislation enacted on December 4, 1991. The enabling legislation, Public Law 102-182, removed restrictions contained in the Comprehensive Anti-Apartheid Act of 1986. Prior to enactment, the regulations prevented U.S. collectors and others from acquiring or importing for exhibition numismatic gold coins of Soviet origin. (See table 1.)

Strategic Considerations

Gold is not a National Defense Stockpile item; however, the Treasury had stocks of bullion amounting to about 8,146 metric tons (262 million ounces) at yearend 1991. Large quantities of gold were also held as commercial and private bullion stocks. Therefore, the availability of gold in times of national emergency appears to be ensured.

One strategic aspect of the domestic gold mining industry that is infrequently considered is that the industry constitutes a valuable pool of experienced personnel, including chemists, geologists, engineers, and metallurgists as well as miners, machinists, and heavy equipment operators. In the event of a national emergency, these skills may be readily directed toward the discovery, development, and production of strategic materials.

Issues

An issue of continuing concern to domestic exploration companies, gold producers, and to producers of other minerals as well is that of mineral land availability. Because the geological forces that form mountains and unique physiographic features are commonly responsible for producing mineral deposits, exploration for gold and other minerals frequently focuses on these areas of disturbance. The same rugged features that make certain areas attractive to the minerals explorer may also make them

less accessible for mining because these areas may presently be more valued for their undisturbed or wilderness qualities than for their mineral potential. In recent years, the trend toward preserving increasingly greater areas of unevaluated wilderness land, on which exploration is prohibited or severely restricted, may lead to a decline in new discoveries as well as jeopardize national security.

Another issue of concern to the mining industry as well as law enforcement authorities has been the recent growth in telemarketing fraud and investment swindles involving sales of gold bullion and investment in questionable mining ventures. In late 1988, the North American Securities Administrators Association Inc. (NASAA) and the Council of Better Business Bureaus Inc. issued an Investor Alert entitled "Dirt Pile Gold Swindles." The alert was to educate the public regarding the organization, characteristics, and pitfalls of the classic "dirt pile" or "gold-in-the-ground" swindle. The NASAA is composed of representatives from the securities regulatory agencies of all 50 States plus Puerto Rico. Law enforcement authorities and various industry trade groups continue to police against other fraudulent practices, such as misrepresented gold quality marks on jewelry and bullion and faked collector coins.

Production

Of the 290 metric tons of gold (9.3 million ounces) produced in the Nation in 1991, 75% was attributable to the 25 leading producers. The average recoverable gold content of precious metals ores processed from lode mines was 0.84 gram per metric ton (0.02 ounce per short ton), while placer gravels yielded an average of 0.82 gram per cubic meter (0.02 ounce per cubic yard) of material washed.

The individual company production and performance data in this report were derived from published sources such as company annual reports.

Alaska.—Despite a 5% increase in gold production in Alaska during 1991, the value of that production declined 6% according to a survey of 1991 mineral activity prepared by the Alaska State Division of Geological and Geophysical Surveys (DGGS).⁵ Gold production of about 3,196 kg (102,754 ounces) was reported to the U.S. Bureau of Mines. However, the annual survey conducted informally by the DGGS suggests that a total of about 7,585 kg (243,900 ounces) of both lode and placer gold was produced; the comparable total for the previous year was 7,206 kg (231,700 ounces). The DGGS noted that placer production stabilized but fewer mines operated during the year; about 202 in 1991 compared with 216 in 1990. This decline reflects lower gold prices, exhaustion of resources in some areas, and increasing regulatory requirements. Placer mining, following a pattern established many decades ago, continued to be a small-business oriented industry providing many jobs to rural Alaska. Reported expenditures for exploration, 83% of which was for gold exploration, declined 40% overall in 1991. The one exception was exploration spending in south-central Alaska, which increased 17% over that of 1990. On October 15, 1991, the State's Reclamation Act, passed in 1990, came into effect. The new regulations require reclamation of all lands currently mined in Alaska, regardless of land ownership.

Greens Creek Mining Co.'s Greens Creek Mine, on Admiralty Island, was the State's largest gold-producing lode mine. Production during 1991 amounted to 1,150 kg (37,000 ounces) of gold plus major values in lead, silver, and zinc. Exploration of the site during 1991 resulted in the discovery of enough additional ore to effectively double the mine's proven and probable reserves. The company, held by Kennecott, Hecla Mining Co. CSX Corp., and Exalas Resources Corp., also made a number of operational improvements to the mine, including increasing mill capacity and implementing additional cost-cutting measures.

Near Cantwell, the Valdez Creek Placer Mine of Valdez Creek Mining Co., managed by Cambior Alaska, was reopened and produced almost 1,327 kg (42,680 ounces) during the year. Mining at the site had been suspended in October 1989 to allow diversion of Valdez Creek to gain access to gold-bearing gravels. The diversion was completed in March 1991 and, by the fall, the daily mining rate had reached almost 19,800 cubic meters (25,800 cubic yards). The company has set a production target of 3,110 kg (100,000 ounces) for 1992. Near Nome, Alaska Gold Co. continued to operate two Yuba class bucket-line stacker dredges onshore, processing thawed gold-bearing gravels. Large placer operations were also active near Fairbanks, Hogatza, Livengood, Ruby, Candle, and Manley Hot Springs.

Permitting difficulties at LaTeko Resources Ltd.'s Ryan Lode property led to the suspension in late 1990 of most of the mine's heap-leaching facilities at the mine site near Fairbanks. During 1991, the mine's new operator, Gateway Mining Co., concentrated on expanding the mine's ore reserves and initiating a program aimed at lengthening the productive operational season. Twenty-four km (15 miles) northeast of Fairbank, mine development work continued at the Fort Knox Joint Venture, which is 51% held by Fairbank Gold Ltd. and Gilmore Gold Inc. Feasibility work done during the year reportedly indicated that the property can be mined profitably as a large-scale open pit operation producing between 9,300 and 10,900 kg (300,000-350,000 ounces) of gold annually. Proven and probable reserves at Fort Knox amounted to 100 metric tons (3.2 million ounces) at yearend. Some of the work performed during the year included "condemnation" drilling to delineate barren sites for future mine infrastructure. In mid-September, Amax Gold Inc. announced its intention to purchase all the assets of the project and to proceed toward developing a producing mine by late 1984 or early 1995.

In southeastern Alaska, Echo Bay Mines Ltd. continued to perform environmental and permitting work at its

Alaska Juneau (AJ) Mine immediately behind the capital city of Juneau. A feasibility study updated to yearend by Echo Bay and its partner W.G.M. Inc. called for a large-volume underground mine and mill able to process 20,400 metric tons per day (22,500 short tons). At this rate, the property was expected to yield 11,660 kg (375,000 ounces) of gold per year for 13 years. The AJ produced more than 93 metric tons (3 million ounces) of gold between 1901 and 1944, when it was closed by increased taxes and labor shortages stemming from World War II. Echo Bay also owns the old Treadwell Mine on Douglas Island, 1.6 km (1 mile) west of Juneau, across the Gastineau Channel. Treadwell, also a former producer, yielded more than 93 metric tons (3 million ounces) of gold from underground between 1882 and 1917. One hundred and fifteen km (72 miles) north of Juneau, Echo Bay and its equal partner Coeur d'Alene Mines Corp. continued underground development work and exploration at their Kensington property, also a former gold producer. Nearby, Placer Dome U.S. Inc. continued to explore the Jualin Mine. Drilling on the property since exploration began in 1987 has amounted to more than 24,400 meters (80,000 feet). Although Placer withdrew from the project at yearend, other companies were expected to continue working there in 1992.

Early in 1991, Tri-Valley Corp., of Bakersfield, CA, formed a unique joint venture with TsNIGRI (Central Research Institute of Geologic Prospecting for Base and Precious Metals) of Moscow. Tri-Valley, which controls a large area of claims in the Richardson mining district 113 km (70 miles) southeast of Fairbanks, was approached by TsNIGRI in 1990. TsNIGRI was looking for a large, varied U.S. property like Tri-Valley's on which to demonstrate its expertise and unique exploration techniques applicable to the discovery of blind or hidden ore bodies. A Russian field crew spent the summer in the Richardson claims area. However, regulatory and political obstacles delayed the completion of crucial work until 1992.

A report⁶ was published summarizing a 1-year effort by Federal, State, and private interests to establish contacts with the neighboring Siberian mining industry. The report summarizes the results of visits by the U.S. team to Siberian gold fields and a reciprocal visit by Soviet mining personnel to Alaska. The report also reviews the history, geotechnical, and climatological settings of the eastern U.S.S.R., the mining industry in Magadan Oblast, Soviet surface and underground mining and processing techniques, and recent developments in these fields. The applicability of Soviet placer technology to Alaska is discussed. Pertinent Soviet technical references are included.

Arizona.—About one-quarter of the gold recovered in Arizona annually is recovered as a byproduct of copper mining; the remainder was recovered from several lode mining operations, the largest of which was Cyprus Gold Co.'s Copperstone Mine near Quartzite in LaPaz County. Copperstone, first opened in 1987 and operated by Cyprus Copperstone Gold Corp., is an open pit facility employing milling and heap leaching plus CIP recovery methods; operation of the heap-leaching facility was begun in 1991. Gold production during the year amounted to about 3,800 kg (112,000 ounces). In an effort to replace rapidly depleting reserves at the mine, the company was reportedly conducting exploration at its newly acquired Bronco Verdestone Oakland property in neighboring Yuma County.

Following construction delays during 1990, South Atlantic Ventures Ltd. began operation at its Oracle Ridge Mine in late February. Oracle Ridge, primarily a copper mine, also produces gold and silver as byproducts. During 1991, the property was expected to yield about 50 kg (1,540 ounces) of gold and 560 kg (18,000 ounces) of silver.

Underground mining was begun in early 1991 at the small but high-grade Mystic Mine. Milling of stockpiled ore began on-site at the end of the year. The owner, Fischer-Watt Gold Co. Inc., holds a 100% operating interest in the mine,

about 19 km (12 miles) north of Sun City in Maricopa County.

In October, Republic Goldfields Inc., formerly Mylartic Hygrade U.S. Inc., completed the first full year of production at its underground Congress Mine in Yavapai County. Also in Yavapai County, in the Big Bug District, gold-silver-copper concentrate shipments were begun in July from the newly reopened McCabe Mine. The initial 3-year mining plan at the underground operation reportedly called for the production of about 270,000 metric tons (300,000 short tons) of ore containing about 2,800 kg (90,000 ounces) of gold, 11,000 kg (350,000 ounces) of silver, and 725 metric tons (1.6 million pounds) of copper during the 3-year period. The mine is operated by Magma Gold Ltd., a newly organized gold mining subsidiary of Magma Copper Co. of San Manuel, AZ.

Gold exploration and mine development continued at a number of sites in Arizona during the year. Pima Mining, formerly Wounded Bull Resources NL, continued exploration and permitting activities at its Newsboy property near Wickenburg in Maricopa County. The company expects to bring the property into production in 1992.

In southeastern Cochise County, venture partners Placer Dome U.S. Inc. and Oneida Resources Inc. continued exploration work on their Mexican Hat project. However, ore reserves developed during an earlier drilling program were believed to be insufficient under existing market conditions. Work was continued on the Yarnell property in Yavapai County as the new owner, Bema Gold Corp., made plans to begin production in 1992 at a rate of about 1,000 kg (32,000 ounces) per year.

California.—The State of California was, for the fifth consecutive year, the Nation's second largest gold-producing State.

In Imperial County, Goldfields Mining Corp. celebrated the pouring of the millionth ounce (31.1 metric tons) of gold produced at its Mesquite Mine near Brawley. Mesquite began open pit and

heap-leaching recovery at the site in early 1986. The April celebration coincided with the opening of the company's "Mesquite Mine Overlook Trail," a self-guided, 1.3-km (0.8 mile) trail that introduces the public to the gold mine and its unique desert environment. The trail, a cooperative effort between Goldfields and the U.S. Bureau of Mines, is marked with numbered posts corresponding to printed information on plant life, environmental protection measures, the mining process, and surrounding geological features. To the east, and also in Imperial County, Glamis Gold Corp. continued its surface mining operations at the Picacho Mine, concentrating on expanding the capacity of its heap-leaching and gold recovery facilities. By late 1991, gold production at the mine had reportedly been increased by almost 60% over that of the previous year. The first full year of mining operations at the company's open pit Yellow Aster Mine in the Randsberg District of Kern County were completed in midyear. Glamis continued engineering and design activities at its nearby Baltic Project, where mining is scheduled to begin in mid-1992. In April, Glamis completed mining operations at its Alto Mine in Calaveras County. Leaching of the remaining ore and site reclamation were continuing at yearend. At Lac Minerals Ltd.'s wholly owned Colosseum Mine in San Bernardino County, 1991 gold production amounted to 1,907 kg (61,310 ounces). An active revegetation program was continued and included a new cactus reclamation project that involved thousands of yucca and agave cacti transplants and seed test plots.

Mining at Homestake's McLaughlin Mine yielded 8,172 kg (262,719 ounces) of gold during 1991, 2% less than that produced during the previous year. During the year, the mine received several commendations, including an award from the U.S. Bureau of Land Management, for innovative waste containment, reclamation, and environmental practices. The mine, near Lower Lake, about 113 km (70 miles) north of San Francisco, is the site of the first successful commercial application of

the autoclave process technology for the extraction of gold.

Two new gold mines reached the final development stages before entering the planned startup phase in early 1992; Viceroy Gold Corp.'s Castle Mountain Project in San Bernardino County and Amax Gold's Hayden Hill Mine in Lassen County were projected to produce annually about 3,100 kg (100,000 ounces) and 4,500 kg (145,000 ounces), respectively. At yearend, several other gold properties were in various stages of exploration or preproduction development.

A new California State law was signed in November eliminating the use of plastic pipes as mining claim markers. The new law specifies that only wood, stone, solid metal, or capped metal pipe markers can be used to mark claims on Federal lands in the State. The law also reduces the number of markers required for outlining a claim to five. Plastic or PVC pipe markers were determined to pose a potential wildlife entrapment hazard.

Colorado.—Gold mine production in Colorado declined for the fourth consecutive year, as lower metal prices and higher costs at Colorado's mostly underground mines led to closure or suspension at several operations producing during the previous year. Some projects under development were also delayed from opening. Among the mines affected by weaker gold prices were the Sunnyside Mine at Silverton, in San Juan County, closed in August by the owners, the San Juan County Mining Venture. Sunnyside production during the year amounted to 100 kg (3,228 ounces). The Alma London Venture near Fairplay, in Park County, was temporarily closed following the completion of an exploration drifting and surface drilling project by partners Alma American Mining Corp., Cobb Resources Corp., and American Boulder Gold Inc.

At Galactic Resources' Summitville Mine near Del Norte in Rio Grande County, all economic ore was mined out and placed on the leach pad by October. The company expected that leaching of

the ore would continue through the first half of 1992. Detoxification of the leach pad was expected to begin at the end of the first quarter of 1992 with reclamation of the heap to follow. Site reclamation had been an ongoing process with substantial reclamation activities occurring during 1990 and 1991. Gold production during 1991 amounted to 1,865 kg (59,978 ounces).

On the positive side of the ledger, Battle Mountain Gold Co. poured the first bar of production gold at its new open pit San Luis Mine, near the town of San Luis, in Costilla County. The new mining and milling operation recovered 684 kg (22,000 ounces) of gold and 435 kg (14,000 ounces) of silver during 1991. A series of startup problems continued to hamper operations for most of the year. Battle Mountain expected to recover almost kg (70,000 ounces) of gold and more than 1,200 kg (40,000 ounces) of silver during 1992. The mine employed 105 people with an annual payroll of \$3.5 million.

In Teller County, the Cripple Creek and Victor Gold Mining Co, a joint venture of Pikes Peak Mining Co., a wholly owned NERCO subsidiary, and Golden Cycle Gold Co. resumed mining of its Ironclad and Globe Hill properties in the Cripple Creek District and initiated crushing and leaching of newly mined ore near yearend. The joint venture continued evaluating its new Cresson Valley Project. Exploration drilling during 1990 and 1991 identified more than 62 metric tons (2 million ounces) of total gold reserves and deposits for the joint venture. In March, the partners marked the 100th anniversary of gold mining in the Cripple Creek District. All metal production during the year came from the Mine Dump Program and amounted to 483 kg (15,519 ounces) of gold and 326 kg (10,475 ounces) of silver. Under the mine Dump Program, dump material from old mines in the district, including the old Cresson Mine, is collected, crushed, and processed by heap leaching. Similarly, Solution Gold Inc. of Golden was also reportedly engaged in reclaiming and reprocessing

dumps in the Central City District in Gilpin County.

Legislation was enacted in Colorado during 1991 removing the ceiling on reclamation security bond requirements from small miners and giving local government and the public greater participation in the permitting process.

Gold occurrences of Colorado were detailed in a study published by the Colorado Geological Survey.⁷ The study discusses both Colorado's well-known deposits and more recently described occurrences, including hot-spring-and detachment-fault-related gold. Gold-bearing proterozoic massive sulfide deposits are discussed, and current theories on the tectonic setting and history of Laramide-Tertiary age gold deposits are presented. Production data for selected Colorado mining districts and an extensive bibliography are included.

Idaho.—Exploration activity in Idaho during 1991 declined about 50% from that of the previous year, according to a review of State activities prepared by the Idaho Geological Survey.⁸ The principal target of the 42 advanced exploration projects in Idaho was gold. Only two of six properties scheduled to begin production in 1991 actually reached maturity.

The two new gold mines beginning production during the year were Pegasus Gold's Black Pine Mine and U.S. Antimony Corp.'s (USAC) Yellow Jacket Mine. Changes in the mine plan and subsequent delays in regulatory approval put off startup at the Black Pine operation from midyear to late fall. Mining of ore began at the Black Pine, in Cassia County, with production from the Tallman pit crushed and loaded on the finished portions of the leach pad. Commercial metal production was not achieved until soon after the beginning of the new year. Black Pine was expected to yield about 1,900 kg (60,000 ounces) per year when fully operational. In Lemhi County, USAC opened its Yellow Jacket Mine in May following a period of operational fine-tuning at the new mill.

In Valley County, Hecla completed mining at its Yellow Pine Unit east of

Yellow Pine. The mine produced 546 kg (17,542 ounces) of gold during 1991. Leaching of the existing heaps was expected to be completed during 1992 for a projected 1992 yield of about 160 kg (5,000 ounces) of gold. During 1991, the Yellow Pine Unit was awarded the State of Idaho's "Excellence in Operation Award" for its environmental stewardship. Seasonal mining of ore at the nearby Stibnite Mine was begun in June by the mine's new owners, MinVen Gold Corp. Modification by MinVen to the plant facilities was expected to increase seasonal production to about 930 kg (30,000 ounces) per year. Idaho Gold Corp., an 85%-owned subsidiary of Bema Gold Corp., continued open pit mining and heap leaching at its Champagne Mine, 32 km (20 miles) west of Arco, in Butte County.

New gold mines that were earlier expected to begin production during 1991 but were delayed by low gold prices and permitting problems, included the following properties: FMC's Beartrack property near Salmon in Lemhi County; Grouse Creek Mining Corp.'s Grouse Creek Mine near Stanley in Custer County; Idaho Gold's Buffalo Gulch property near Elk City, Idaho County; and NERCO's Stone Cabin property in Owyhee County. NERCO's large open pit Delamar Mine, 8 km (5 miles) from the Stone Cabin property, produced 1,150 kg (37,000 ounces) of gold and almost 53 metric tons (1.7 million ounces) of silver during 1991.

Montana.—According to an annual review of mining development, prepared by the Montana Bureau of Mines and Geology,⁹ 207 exploration licenses were active in the State during 1991, up 14 from the previous year. As in recent years, the primary exploration target was gold but interest in other metals, such as copper, lead, and zinc, was increasing. The increase in exploration licenses apparently reflected a sharp increase in activity by private individuals in place of established corporate interests that dominated exploration in earlier years. All mineral activity in Montana, whether on private, State, or Federal land, is

regulated by the Montana Department of State Lands under three classes of permits—Small Miner Exclusion licenses, exploration licences, or operating permits. Despite a 42% increase in gold production, Montana retained its rank as the Nation's fourth largest gold-producing State.

Montana's leading gold-producing company, Pegasus Gold, began the year with four producing gold mines. During the last quarter, however, continuing weakness in the gold price forced Pegasus to suspend operations at its Basin Creek Mine in Lewis and Clark County. Mines remaining in operation were the Zortman-Landusky Mine in Phillips County; the Beal Mountain Mine south of Butte in Silver Bow County; and the Montana Tunnels gold, lead, silver, and zinc mine, 37 km (23 miles) south of Helena in Jefferson County. Production at the Zortman-Landusky operation, which consists of two separate surface mines several kilometers apart, established a new record for both gold and silver production at 3,617 kg (116,300 ounces) and 29,700 kg (954,000 ounces), respectively. The production increase was attributed to higher ore grades and an increase in tons mined from 11.8 million metric tons (13 million short tons) in 1990 to 12.9 million metric tons (14.2 million short tons) in 1991. Pegasus reduced its cash operating costs during 1991 to \$214 per ounce, from \$225 per ounce in the previous year. Gold grades of ore-in-process on the Landusky side of the dual mine operation were reported to be 0.51 gram per metric ton (0.015 ounce per ton), well below the cutoff grade at many similar operations elsewhere. Heap-leaching recovery methods are used at Zortman-Landusky. At the Beal Mountain Mine, Pegasus constructed 93,000 square meters (1 million square feet) of new leach pad area and doubled the capacity of its treatment plant. Production during the year amounted to 1,471 kg (47,300 ounces), down 5% from that of the previous year. Following last year's modification to the mining plan and treatment plant, gold production at the company's Montana Tunnels Mine rose 6% to 1,928 kg

(62,000 ounces), while operating costs were trimmed by 10%.

In Southern Jefferson County, production at Placer Dome's 100%-held Golden Sunlight Mine declined 18%, to 2,487 kg (79,963 ounces), primarily owing to mining of lower grade transitional ore. The complex metallurgical characteristics of the ore also led to lower recovery rates. The transition to higher grade ores was expected to result in an increase in production during 1992. In Fergus County, Canyon Resources Corp. completed its first full year as owner of the Kendall Mine. Improvements implemented under Canyon resulted in production of 1,775 kg (57,070 ounces) of gold, nearly double that of the previous year. Exploration during the year at Canyon's 27.6%-held Seven-up Pete Joint Venture in Lewis and Clark County led to the discovery on the partner's McDonald Meadows property of a sizable gold deposit with a geologic reserve estimated at yearend to contain about 168 million metric tons (185 million short tons) grading 0.96 gram per metric ton (0.028 ounce per short ton). Near Maiden, in Fergus County, Blue Range Mining Co. reportedly produced a small amount of high-grade ore from its McGinnis property adjacent to the now dormant Spotted Horse Mine. The company's Geis and Gilt Edge Mines did not produce during 1991. East of Jardine in south-central Park County, Homestake and TVX Mineral Hill Inc. produced about 1,330 kg (42,700 ounces) of gold at their jointly held Mineral Hill Mine. To minimize the environmental impact by mining on the environmentally sensitive area north of Yellowstone National Park, mining is conducted underground and a dry tailings system is employed to help maintain the zero discharge design of the surface milling and recovery facilities. Because the Mineral Hill project is within the historic town of Jardine, the company works closely with the State Historic Preservation Office to ensure preservation of the town's cultural resources. Precautions were also taken to minimize the impact on wildlife by the project. As part of a longer term exploration

program, drilling was continued on patented and U.S. Forest lands held by the joint venture in the Crevasse district east of Jardine.

Exploration and preproduction development work was continued during the year at a number of properties associated with or within the same districts as most of the aforementioned producers. Similarly, many generally small, intermittent placer mines were active, mostly on a seasonal basis, during 1991.

Nevada.—America's continuing position as one of the world's largest gold-producing nations depends on, to a certain extent, developments in the State of Nevada. Nevada, by far the Nation's dominant gold-producing State, produced 39% of the national total. Fourteen of the Nation's leading 25 gold mines in 1991 were in Nevada. Gold is the State's principal mineral commodity, accounting for 87% of the value of its nonfuel mineral output during 1991.

Newmont Gold Co. (NGC), the Nation's dominant gold-producing company, produced about 49,100 kg (1.58 million ounces) from its mining operations in Eureka and Elko Counties. NGC's total production during the year was derived from four surface mines feeding five nearby mills and three heap-leaching facilities. The company's total cash cost of production was reduced to \$203 per ounce during 1991 compared with the previous year's average of \$218 per ounce. Proven and probable ore reserves on NGC's Nevada properties increased by 6% to 625 metric tons (20.1 million ounces), the second largest ore reserve position on the continent. In December, the company's open pit Gold Quarry Mine became the first mine in North America to produce more than 1 million ounces of gold (31.1 metric tons) in a single year. The Gold Quarry Mine was commissioned by NGC in 1985, and during that year it produced 3,312 kg (106,500 ounces). It is the largest of the company's 16 deposits generally centered around the town of Carlin in northern Eureka County. During the year, NGC researched methods to treat its large

resource of refractory ores. A decision was made in midyear to build a roasting plant in conjunction with its existing mill facilities in the company's south area of operations at Carlin. The company's research into bioleaching of low-grade gold-bearing refractory materials advanced during the year to the stage where patent protection was sought.

During 1991, the Goldstrike Mine, of American Barrick Resources Corp. adjacent to NGC's Eureka County operations, set records for mining and gold production, exceeded design capacity for autoclave and mill throughput, and achieved greater-than-anticipated cost reductions. The mine moved 116 million metric tons (128 million short tons) of ore and waste during the year, recovering 16,927 kg (546,146 ounces) of gold. Goldstrike was expected to yield 28,000 kg (920,000 ounces) of gold during 1992. Of the total 1991 production, 59% was recovered using heap leaching, while the remainder came from milled oxide and sulfide ores. The company's Betze open pit was the principal source of ore. The company's new autoclave unit completed its first full year of operation, exceeding its design capacity by 32%. Barrick expected to have three additional autoclaves on-line by early 1993, thereby completing its 4-year Betze Development Plan, begun in 1989.

In Elko County, northeast of the Goldstrike-Carlin Operations, partners Independence Mining Co. Inc. and FMC Gold Co. achieved the highest level of gold output at their Jerritt Canyon Mine since production began in 1981; production for the year amounted to about 11,700 kg (376,700 ounces). Exploration during 1991, especially at the New Deep deposit, 11 km (7 miles) west of the mill site, led to a 33% increase in gold contained in proven and probable reserves.

Overall, 15 separate gold deposits have been discovered in the area comprising Jerritt Canyon operations; two deposits have been depleted since mining began in 1981. Independence continued open pit mining operations at its wholly owned Big Springs Mine, 16 km (10 miles) north of Jerritt Canyon. Other mines

operating in Elko County during 1991 included Dee Gold Mining Co.'s open pit Dee Mine, which produced 1,308 kg (42,046 ounces) of gold during the year, and Ivanhoe Gold Co.'s new Ivanhoe (Hollister) Mine, which completed its first full year of operation, producing 1,865 kg (59,978 ounces) of gold.

To the west, in Humboldt County, Santa Fe Pacific Gold Corp. poured its first bar of production gold at its new Lone Tree Mine southeast of Golconda. The company expected the new open pit facility to produce about 870 kg (28,000 ounces) of gold during 1991 and about 31,00 kg (100,000 ounces) of gold annually thereafter. In August, Santa Fe's nearby Rabbitt Creek Mine completed its first full year of production, producing about 3,600 kg (115,500 ounces) during the calendar year.

Twenty-two km (14 miles) southwest of the town of Battle Mountain, in Lander County, Battle Mountain Gold Co. (BMG) reported gold production of about 7,600 kg (244,000 ounces) from its open pit and milling and heap-leaching operations. Most of the gold produced during the year was derived from the company's Fortitude Mine and from satellite ore bodies. BMG's Copper Canyon heap-leaching facility completed its first full year of production, recovering about 310 kg (10,000 ounces) of gold. To the southeast, St. George Metals Inc. continued preparations to reopen its underground Dean Mine. Production at the Dean was expected to begin in mid-1992.

Twenty five km (16 miles) south of the BMG complex, Echo Bay set a new production record of more than 8,800 kg (284,327 ounces) at its McCoy and Cove gold and silver property. McCoy and Cove consists of large-scale surface and small-scale underground mines using milling and heap-leaching recovery methods. Mining was completed in the McCoy pit in early 1991, but subsequent exploration discovered additional ore that will be recovered when underground mining beneath the pit is completed. Echo Bay's cash costs per ounce of gold produced at McCoy-Cove during 1981 was \$253, compared with \$270 in 1990.

Echo Bay also owns a 50% interest in the open pit Round Mountain Mine at Round Mountain, about 190 km (120 miles) to the south of McCoy-Cove. The company's partners at Round Mountain are Homestake (25%) and Case Pomeroy (25%). During the year, gold production at the facility, all recovered by heap leaching, amounted to 10,543 kg (339,000 ounces), compared with 15,027 kg (483,192 ounces) in the previous year. The lower production was attributed to lower ore grade. The Round Mountain Mine is operated by Round Mountain Gold Corp.

West of Round Mountain near Gabbs, also in Nye County, FMC Gold Co.'s Paradise Peak gold and silver mine celebrated the February pouring of its millionth ounce of gold (31.1 metric tons) since beginning production in early 1986. The quantity of ore processed at Paradise Peak by milling and heap leaching rose sharply during the year; however, because ore grades continued to decline as the pit expanded, gold production declined 9% to 5,660 kg (182,000 ounces). Silver production declined sharply to 2.3 million ounces, reflecting the depletion in 1990 of the mine's high-grade silver ore. Near Beatty in southern Nye County, U.S. Nevada Gold Search Joint Venture completed mining at its Mother Lode Mine. Other gold and silver mines continuing operations in the Beatty area included the Bullfrog Mine, Gold Bar Mine, and the Sterling Mine.

North and west of Ely in White Pine County, U.S.M.X., Inc. continued to produce gold from its Alligator Ridge, Casino, and Green Springs Mines and began production at its Winrock Mine. Development of the company's Yankee Project began in September, and contract mining was begun in October. Metal production at Yankee was expected to begin by mid-1992.

Numerous other mines throughout the State continued to produce gold. Several mines were at various stages of preproduction, and several other properties were closed owing to depletion or unacceptable economic factors.

A paper published by the Bureau during 1991¹⁰ evaluated the factors

responsible for the tremendous resurgence of Nevada gold production over that of neighboring California. It was noted that the contrasting levels of success are not an effect of geologic favorability, but rather of differences in the political and regulatory climates between the two States.

Oregon.—According to a State report¹¹ on mining and exploration in Oregon, there were no primary lode gold mines producing in Oregon during the year. There were, however, several active placer mines, including Bonanza Mining Co.'s mine on Pine Creek in Baker County.

In early 1991, Formosa Exploration Inc. reportedly began mining gold- and silver-bearing zinc and copper ore at its underground Silver Butte Mine in Douglas County near Riddle. Owing to a forest fire hazard the mine was reportedly forced to close near yearend.

Though exploration was continued at a number of gold properties during the year, concern over the regulatory future affecting both exploration and future development reportedly contributed to a decline in exploration generally. More companies terminated Oregon projects in 1991 than initiated projects. Concern over regulations was heightened during the year when the State legislature passed a House bill referred to as the Chemical Process or Cyanide Heap Leaching bill. The measure overhauled the State's mining regulations by proposing a number of administrative changes, including a lengthy permit process and backfilling of open pits in special cases. At yearend, the State Environmental Quality Commission determined that objectionable aspects of the proposed ruling on chemical process mining will be subject to technical review by a third party.

Delays in permitting at Atlas Corp.'s Grassy Mountain project in Malheur County were reportedly related to the regulatory climate. Atlas had originally expected to begin mine construction at Grassy Mountain in 1992. The mine, as originally envisioned, was to produce more than 3,100 kg (100,000 ounces) of

gold per year and provide employment for almost 200 people from the largely agricultural area surrounding the site.

A 100-year-old ditch built by Chinese laborers in their search for gold near Myrtle Creek, in Douglas County, was listed on the National Register of Historic Places. The Bureau of Land Management announced in late July that 18 km (11 miles) of China Ditch had been listed on the register in recognition of the most ambitious and longest water diversion for gold placer mining in western Oregon.

South Carolina.—As in previous years, gold production data for South Carolina have been withheld in this publication to avoid disclosing company proprietary data. South Carolina's principal gold mines in operation during the year were the Ridgeway Mine in Fairfield County, the Haile Mine in Lancaster County, the Brewer Mine in Chesterfield County, and the Barite Hill Mine in McCormick County.

Brewer Gold Inc., a subsidiary of Westmont Mining Inc., temporarily ceased mining activities at the Brewer Mine in late 1990 following the failure of an earthen tailings dam at the mine site. Following construction of a new dam, mining operation were resumed in mid-1991.

South Carolina's largest gold mine, the Ridgeway Mine of Ridgeway Mining Co., a joint venture between RTZ and Galactic Resources Ltd., produced 4,406 kg (141,665 ounces) of gold during the year. The mine, comprising two open pits 1.6 km (1 mile) apart, recover gold by conventional milling and carbon-in-leach processing. Difficulties in compensating for harder ore from the north pit resulted in an 18% decline in production from that of the previous year. Ridgeway is the largest gold mine in the Eastern United States.

At the Haile Mine near Kershaw, Piedmont Mining Co. ceased mining and heap stacking activities in August to prepare for the resumption of mining on a much larger scale in 1992. Leaching and gold recovery operations were continued into 1992. Production for the

year was 327 kg (10,517 ounces), compared with 697 kg (22,402 ounces) in 1990. In March, Piedmont signed an agreement with Amax Gold Exploration Inc., a wholly owned subsidiary of Amax Gold. An exploration program begun in April resulted in a 130% increase in minable ounces of gold on the Haile property.

In March, the first bar of production gold was poured at the new Barite Hill Mine near McCormick, about 19 km (12 miles) north of Augusta, GA. The new open pit and heap-leaching facility, the State's fourth producing gold mine to be opened in recent years, is expected to yield about 640 kg (20,500 ounces) of gold and more than 1,900 kg (61,000 ounces) of silver per year. Barite Hill was developed by Gwalia (U.S.A.) Ltd., a subsidiary of Gwalia International Ltd. of Australia. The mine is surrounded by several long-abandoned gold mines, including the old Dorn Mine, which produced gold between the 1850's and 1930's.

Gold exploration was conducted on a moderate scale elsewhere in South Carolina as well as in several other southern States from Virginia through Alabama.

South Dakota.—Despite greater gold production in South Dakota during 1990 and 1991 when compared with that of 1989, lower gold prices and higher production costs severely impacted tax revenues for the State from gold mining. Combined tax revenues reportedly decreased 35% during the 1990 and 1991 period. Gold is the principal mineral commodity produced in South Dakota.

The State's principal gold-producing mine is the Homestake Mine at Lead. Except for a brief period during World War II, the mine has been operating continuously under the same ownership since 1877. Total cumulative production surpassed 1,135 metric tons (36.5 million ounces) in 1991, thus making the mine one of the most productive gold operations in the world. The operations at Lead include an underground mine; an open pit, known as the Open Cut, on-site of the original gold strike in 1876; a mill;

and a gold refinery. During the year, Homestake produced 9,924 kg (319,080 ounces) or 18% less than that in the previous year. The decline was attributed to a 17% drop in tons of ore mined underground together with an 11% decline in underground ore grade. A temporary shortage of experienced miners reduced the ability of the company to adjust operations to adequately compensate for the grade shortfall. To offset the tonnage loss during the year from the underground mine, lower grade Open Cut ore was supplied to the mill to maintain full milling rates. As a result, average grade processed through the mill dropped 15%, and the gold recovery rate was slightly lower. During the year, Homestake increased its total annual milling capacity by 8% to 2.54 million metric tons (2.8 million short tons). The \$11 million mill optimization effort was expected to increase future production by about 950 kg (30,000 ounces) annually. The company continued to work on its new North Homestake Project, and an exploration tunneling program that was begun in 1990 to explore deep gold mineralization discovered earlier about 5 km (3 miles) north of the existing workings. Tunneling was advanced about 1,500 meters (4,900 feet) during the year and, at yearend, stood at a total of more than 2,000 meters (6,600 feet).

South Dakota's second largest gold mine, Wharf Resources (USA) Inc.'s Annie Creek-Foley Ridge property, reportedly produced a record 2,910 kg (93,569 ounces) of gold during 1991. The open pit and heap-leaching operation is 5 km (3 miles) west of Lead. Cold weather conditions during February and March curtailed leaching operations at the Golden Reward Mine, 13 km (8 miles) southwest of Lead. The operator, Golden Reward Mining Co., is a joint venture between MinVen Gold and United Coin Mines Ltd. During 1991, the owners agreed in principle to merge United Coin into MinVen. The mine, a seasonal operation, is scheduled to produce 2,020 kg (65,000 ounces) during 1992 with production planned to increase to 2,490 kg (80,000 ounces) by 1994. At MinVen's 100%-held Gilt Edge Mine 8

km (5 miles) southwest of Lead, also an open pit and heap-leaching operation, production during the second quarter was adversely affected by unusually heavy rainfall, which damaged the solution containment system. Permanent repairs were completed by the end of the third quarter.

Bond Gold Richmond Hill Inc. reported recovering 1,300 kg (41,815 ounces) of gold during the year at its Richmond Hill property 8 km (5 miles) northwest of Lead. Exploration activities were concentrated around the open pit with an emphasis on the development of minable ore reserves. These efforts have been so far unsuccessful. The mine's existing reserves are expected to be mined out in 1992, but heap leaching will continue until the heaps are depleted of metal.

Following several years of test processing, production was resumed at the Red-Ex placer mine along Whitewood Creek near Deadwood. The mine, operated by Dakota Placers Inc., is expected to recover about 310 kg (10,000 ounces) of gold per year plus values in silver when fully operational. The Whitewood Creek Tailings Project in Butte, Lawrence, and Meade Counties was placed on hold by the owners, Goldstake Explorations (SD) Inc., pending an improvement in gold prices.

In mid-1991, the final draft of the Cumulative Environmental Evaluation (CEE) on mining in the Black Hills was submitted to the State Board of Minerals and Environment. The CEE, part of the State's Environmental Act, was conducted in conjunction with a 2-year moratorium on new mines beginning in February 1990. The CEE proposed a 2,430-hectare (6,000 acre) limitation on large-scale surface gold and silver mining in the Black Hills and a requirement that, by 1997, major mining companies reclaim 200 hectares (500 acres) of land disturbed by mining. Other recommendations call for reporting requirements, protection of critical resources, financial assurances for cyanide cleanup, and development of post-closure plans.

Utah.—Kennecott Corp.'s Bingham Canyon Mine continued to be one of the Nation's principal gold- and silver-producing mines, ranking third in the Nation in gold production during 1991. The mine, owned by RTZ and operated by Kennecott, produces gold and silver as byproducts of its copper mining activities. During the year, Kennecott studied the feasibility of expanding its on-site smelting capacity to handle all of its concentrate production, a part of which has been sold for processing elsewhere in recent years. A decision to build a new smelter was announced during the first quarter of 1992. Kennecott also operates the new Barney's Canyon gold mine about 6.4 km (4 miles) north of the Bingham pit.

The Mercur Mine of American Barrick in Tooele County achieved its fourth consecutive year of record production in 1991. The mine's new dump-leaching facilities registered a 58% increase in production from that of the previous year. Gold recovered from milled oxide and sulfide ores declined somewhat from that of the previous year. Total gold production from Mercur's two open pits amounted to 3,958 kg (127,280 ounces) during the year.

About 65 km (40 miles) northwest of St. George in southwestern Utah, Tenneco Minerals continued surface and heap-leaching operations at its Goldstrike Mine. Production at Goldstrike amounted to about 1,400 kg (45,000 ounces) during 1991.

Washington.—Although U.S. Bureau of Mines figures for Washington gold production have been largely withheld over the past decade to avoid disclosing company proprietary data, the Washington State Division of Geology and Earth Resources, in its annual review of the State's mineral industry,¹² noted that gold production increased again in 1991 as it has nearly every year since 1985. The report also noted that accompanying the increase in production, acquisition of mining properties in the State and expenditures for detailed evaluations of these properties during

1991 appeared to have increased relative to those of the previous year.

Gold production at the Cannon Mine, Washington's largest gold mine and the Nation's second largest underground gold mine, amounted to 4,726 kg (152,010 ounces) during 1991; silver production totaled 8,439 kg (271,352 ounces) during the same period. Cannon is a joint venture between Asamera Minerals (U.S.) Inc. and Breakwater Resources Ltd. During 1991, an exploration drift was being driven to intersect gold mineralization discovered by earlier drilling and to confirm drill-indicated reserves. Asamera also conducted exploration on properties that it holds in the Wenatchee area.

At Republic in Ferry County, Hecla's underground Republic Unit, or Knob Hill Mine, produced 2,418 kg (77,736 ounces) of gold and 9,686 kg (311,445 ounces) of silver in 1991, all from the Golden Promise area of the mine, which was discovered in 1984 just prior to the mine's closure owing to exhaustion of reserves. Gold production costs at Republic, among the lowest in the Nation, especially for an underground mine, amounted to \$140 per ounce in 1991. In August, Hecla completed a new decline-ramp connecting the Golden Promise area of the mine to the surface. The decline allows the use of diesel rubber-tired vehicles for loading and hauling ore directly to the surface. Hecla, using the new decline as an exploration base and recognizing the potential for the discovery of additional ore at Republic, embarked in 1991 on an extensive underground exploration program. In anticipation of further discoveries, preliminary engineering work was begun to nearly double the capacity of the mill, if and when new ore is located.

In February, Echo Bay completed its first full year of production at its new Kettle River project near Republic. Production for the full year 1991 amounted to 1,965 kg (63,191 ounces). The project has been developed as a joint venture between Echo Bay, the operator, and Crown Resources Corp. The project, scattered over 5,700 hectares (14,000 acres), has been developed

around five separate deposits. The fifth deposit, the Lamefoot property, was added in late 1991. The Kettle and the Overlook deposits provided mill feed during the year. Both deposits are mined from underground with access provided by decline ramps.

At the Crown Jewel deposit in Okanogan County, joint owners Battle Mountain Gold, the operator, and Crown Resources, conducted extensive drilling focused on delineating the extent of the deposit's gold mineralization. The partners also initiated the process of mine permitting in preparation for mining. Crown Jewel is part of a 3,240-hectare (8,000 acre) property package known as the Crown Jewel Exploration Project. Gold exploration in Washington generally was concentrated in Chelan, Ferry, Okanogan, and Stevens Counties. Of the 106 metallic mineral properties accounted for by the State in its 1991 review, gold was shown to be the primary or secondary target at 90 exploration or development sites. (See tables 3 through 7.)

Consumption and Uses

The use of gold in the domestic market shown in table 9 accounts for only part of the overall market for commercial products. An important segment of market demand is also satisfied by imported gold-bearing products in various forms ranging from unfinished jewelry products, such as gold chain and findings, to electronic equipment containing gold components.

The volume of gold futures traded on the Nation's gold futures exchanges during 1991 declined substantially from that of 1990, owing, in part, to apparent investor disinterest.

Contracts for gold futures traded during 1991 represented about 21,200 metric tons (680 million ounces) compared with those of the previous year, when the equivalent of more than 30,000 metric tons (973 million ounces) was traded. The New York-based Commodity Exchange Inc. (COMEX) was, as in the previous year, by far the dominant exchange.

Sales of newly minted gold coins by the U.S. Mint declined for the third consecutive year. On October 20, the fifth anniversary of the American Eagle gold bullion coin program, the U.S. Mint had sold 168 metric tons (5.4 million ounces) of contained gold, all sourced, as mandated in the enabling legislation, from contemporary domestic gold mines.

Although gold loan activity between commercial depository banks and gold producers generally seemed to have peaked in 1988, it continued to be an acceptable method of financing new mine development or expansion of existing facilities.

Stocks

Yearend stocks of refined bullion held by industrial users increased about 6% over those held at the end of 1990. On a quarterly basis, the greatest decline in industrial stocks was reported during the first quarter of the year and may reflect a withdrawal of material by manufacturers to meet anticipated demand, especially for jewelry products destined for sale later in the year.

Yearend stocks of gold certified for delivery by COMEX, the Nation's largest futures exchange, were essentially unchanged from those held at the end of the previous year.

Markets and Prices

The Engelhard industries/London daily final price of gold ranged from a high of \$404 per troy ounce at the beginning of the war in the Persian Gulf in mid-January to a low of \$345 per ounce in mid-September, its lowest level in more than 5 years. Uncertainty arising from the continuing turmoil in the U.S.S.R. and reports regarding the size of the U.S.S.R. bullion reserves led to a yearend rally that drove the price above \$370 per ounce.

Efforts by the European Commission to require all measurements to conform to the Commission's harmonization policy reportedly were defeated in 1991 by the Bank of England and the London Bullion Marketing Association. The opponents

successfully argued that the troy system of measurement does not easily translate into metric and should therefore be retained for use in the gold and other precious-metals markets.

Foreign Trade

Total U.S. exports of refined gold increased for the third consecutive year. Switzerland was again the principal recipient nation, receiving large quantities of both refined bullion and doré. In addition to Switzerland, Hong Kong and the United Kingdom were also principal destinations for refined bullion shipments.

The surge in late 1991 in total imports was due in part to late 1991 changes in the Customs User Fee as discussed earlier under "taxes." (See tables 8 through 11.)

Canada continued, as it has for more than a decade, to be the Nation's principal source of refined bullion. Imports of refined Canadian bullion during the year increased almost threefold, while similar imports from Uruguay and Brazil increased fivefold and twentyfold, respectively. (See tables 12 and 13.)

World Review

For the 12th consecutive year, world gold mine production has exceeded that of the previous year. In 1991, however, the growth rate slowed appreciably compared with the strong growth rates achieved during the mid-1980's.

In its 24th annual statistical review of world gold supply and demand, Gold Fields Mineral Services Ltd. (GFMS)¹³ observed that for the first time since 1983 the total supply of gold to Western World markets fell by more than 3% from supplies available during the previous year. GFMS' review, like reviews prepared by its predecessor, Consolidated Gold Fields PLC, has, for more than two decades, been as the most comprehensive source of world gold supply and demand data available on a comparable annual basis.

In addressing world gold mine production, the GFMS report noted that the slowdown in world production was

due to a variety of factors, including the increasing difficulty in attracting financing for marginal properties, plus the depletion, scaling-back, or closure of some older mines, thereby offsetting gains in new capacity elsewhere. Gold prices, having fallen to the lowest level in real terms since the early 1970's, impacted both investors and gold mines alike. Although many mines were able to adapt to the lower prices through production cost reductions, the savings gained were often accompanied by lower production. GFMS cautioned, however, that the formal gold mining sector's tenacity and its ability to adapt to lower prices has limitations, especially in high-cost underground mines. Without a price increase, the point at which higher cost operations cease to be economic is rapidly approaching, especially at a number of South African mines.

GFMS notes that the use of gold loaned to the market by producers in return for development capital has been a prominent addition to supplies in recent past years, especially 1988. In 1991, however, according to the GFMS report, lower prices, reduced mine development, and other factors reversed the popularity of gold loans and the net affect was, that for the first time, repayments of gold loans exceeded the demand for new loans by 11 metric tons (354,000 ounces). Forward sales added only 51 metric tons (1.6 million ounces) to the overall supply or about 200 metric tons (6.4 million ounces) less than that in the previous year.

Other components of supply assembled by GFMS in its annual report included net sales of gold from centrally planned economy countries, at 226 metric tons (7.3 million ounces), down 47% from those of 1990; official or central bank sales to the market at 105 metric tons (3.4 million ounces) contrasted sharply with those of the previous year when these institutions absorbed 66 metric tons (2.1 million ounces); supplies of old gold scrap added 410 metric tons (13.2 million ounces) to supplies, down 16% from that of 1990; and inferred disinvestment which, according to GFMS, showed the greatest turnaround during 1991, when

the private sector, which absorbed 173 metric tons (5.6 million ounces) in 1990, disposed of 241 metric tons (7.7 million ounces) during 1991. Most disinvestment was attributed to private investors in Europe and the United States.

GFMS reported that gold jewelry fabrication demand rose by 4% in 1991, the fifth consecutive year of rising demand in that sector. The 1991 increase was the result of inventory building by jewelry distributors and retail outlets, mainly in Europe and the Gulf countries. Also noted was a rapid increase in demand in China. For the first time in the annual GFMS series, estimates of fabrication demand for China and the U.S.S.R. were included.

According to the GFMS report, gold usage in electronics and industrial applications, at 147 metric tons (4.7 million ounces), was essentially unchanged from that of 1990. This was attributed to a sharp decline in computer sales and the first sign of weakening military equipment orders. Dental gold usage rose 5%, continuing a trend begun in 1988. Gold use in medals and invitation coins rose 20% to 23 metric tons (734,000 ounces) while gold used in striking official coins, 150 metric tons (4.8 million ounces), rose 32 metric tons (1 million ounces) over that of the previous year.

Although identified bar hoarding rose 12% during 1991, GFMS noted that when the masking effects of unusual events in Brazil during 1990 and 1991 are factored out, demand in this category actually reached its peak in 1989 and declined thereafter.

Capacity.—Rated annual production capacities for gold mines, as of December 31, 1991, are shown in table 14. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time at a normally sustainable, long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes operating plants and plants temporarily closed that, in the

judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

Because of the size, diversity, and explosive growth of primary gold production over the past decade, comprehensive world capacity data that would include all operating units that contribute to national totals are generally not available. Therefore, in the absence of appropriate data, certain broad assumptions were employed to derive international capacity numbers that are compatible with production data shown in table 15.

Reserves.—Demonstrated U.S. reserves of gold in 1991 were about 4,770 metric tons (about 153 million ounces), and the reserve base was 5,250 metric tons (169 million ounces). Most of the U.S. gold reserve base shown in table 14 is confined to 18 States, with about 80% of the total in Alaska, California, Idaho, Montana, Nevada, and Washington. A dominant portion of the reserve base occurs in lode deposits.

Total world reserves shown in the table approximated 43,000 metric tons (1.38 billion ounces), of which nearly one-half was in the Republic of South Africa. The world reserve base for gold totaled about 49,500 metric tons (1.6 billion ounces). Reserves of gold in the U.S.S.R. were believed to be about 6,220 metric tons (200 million ounces).

Estimates of reserves become available only over an extended period of time. The reserves shown for Australia, Brazil, Canada, and the United States generally reflect post-1980 data and the success of exploration efforts frequently initiated years earlier in response to rising prices. (See table 14.)

Africa.—Despite the continuing burdens associated with weak gold prices, continued currency inflation, and escalating production costs, the Republic of South Africa's gold production fell less than 1% in 1971 to 601,013 kg (19.3 million ounces). Maintenance of this production level was achieved through the use of various cost containment efforts

including, when possible, the mining of higher grade materials, thereby reducing costs associated with mining, milling, and processing. Thus, the gold mining industry milled only 107 million metric tons (118 million short tons) with an average grade of 5.20 grams per metric ton (0.152 ounce per short ton) compared with the previous year's throughput of 111 million metric tons (122 million short tons) bearing 5.05 grams per metric ton (0.147 ounce per short ton). The success of various rationalization or cost containment programs was reflected in a 4.5% or \$14 per ounce decline in cash production costs from those of 1990. Over the past 20 years, however, South African gold mines have gone from being among the lowest cost gold producers in the world to the highest cost producers in 1991. The rate of increase in average production costs of the nearly three dozen mines representing the membership of the Chamber of Mines of South Africa slowed from 10% during 1990 to 4% during 1991.

Production costs for Chamber members ranged during 1991 from a low of \$208 per ounce at Gold Fields of South Africa Ltd.'s (GFSA) Driefontein Consolidated Mine to a high of \$512 per ounce at the 4-year-old H.J. Joel Mine owned by Johannesburg Consolidated Investment Co. Ltd. (JCI).

In terms of individual mine output, in metric tons, the largest South African gold mines during 1991 were the Anglo American Corp. of South Africa Ltd.'s (AAC) Freegold Mine with 113.8; the Vaal Reefs Mine, also owned by AAC, at 73.9; GFSA's Driefontein Mine with 56.8; AAC's Western Deep Levels Mine with 41.4; and GFSA's Kloof operations with 31.9.

The South African gold mining industry is dominated by six major corporate groups or "houses," including AAC, GFSA, JCI, Anglovaal Ltd., Gencor Ltd., and Rand Mines Ltd.

For a number of South African gold mines the past several years have been very difficult years. For many, severe cost cutting measures have resulted in a deferral of the large capital expenditures normally required on a regular basis for

the orderly development required to sustain full capacity in future years. Thus, should the fundamentals of the gold market improve substantially in the future, some operations will be unable to catch up with the rest of the industry without first investing major amounts of time and money. For example, on three different occasions Anglovaal's Lorain Mine in the Orange Free State (OFS) announced rationalization programs to reduce losses by lowering mill throughput and reducing employment. Similarly, Gencor announced plans to close one shaft at its St. Helena Mine also in the Orange Free State and, in June, curtailed operations at its new Wettvreden Mine in the Western Transvaal. The Republic of South Africa's gold mining industry is also very labor intensive, employing large numbers of mostly unskilled and semiskilled workers. With labor costs consuming an ever-increasing share of the working costs, reductions in the overall labor force continue to escalate. As a consequence, the number of people employed at the gold mines had fallen by the end of 1991 to less than 407,000, its lowest level since 1976. Gold Mine employment peaked in 1986 at 534,000.

Exploration for new gold deposits and extensions of existing deposits, reflecting the negative developments in the mining sector, was less active during 1991 than during recent past years when exploration activity delineated several potential new OFS mines such as Gencor's Poplar Mine in the Evander area and JCI's South Deep property adjacent to its Western Areas Mine in the Fochville area. During the year, Anglovaal continued exploration in the Sun and Oripi project areas in the Bothaville Gap area of the northern OFS.

In April, the European Community lifted its 1986 ban on imports of various South African products, including gold Krugerrand coins. Similar steps were taken by the United States in mid-July.

Gold production in Ghana rose 56% above the production reported during the previous year. This growth reflected increased production at Ashanti Goldfield Corp.'s Ashanti Mine at Obuasi as well as the first full year's contribution by three new mines opened in 1990. At the

Ashanti Mine, which has been operating since 1895, the company's new Sansu open pit facility reportedly contributed 4,980 kg (160,000 ounces) to Ashanti's total production of about 18 metric tons (580,000 ounces). The three new mines completing full year operations were Canadian Bogusu Resources Ltd.'s Bogusu Mine, the Pioneer Group and Ghanaian Government's Teberebie operations, and Sikamen Gold Resources Ltd.'s Goldenrae placer mine near Kiki. Several smaller gold mines operated in Ghana during the year while several others were in various stages of preproduction development.

A new gold mine was officially opened in the Republic of the Ivory Coast in November. The new open pit operation, near the village of Ity in the Man region of the country, is jointly owned by a Government subsidiary and Coframines, a subsidiary of France's BRGM. The Ity project, operated by Eden Roc Mineral Corp., of Toronto, Canada, reportedly contains a reserve of about 15 metric tons (500,000 ounces) of gold. Heap-leaching recovery methods are employed to recover the gold.

Australia.—Following 11 consecutive years of growth in gold production, Australian production declined 4% from that of the previous year. This slight decline reflected, in part, weak gold prices, rising production costs, and to some extent the effects of a new tax on gold mining that came into effect on January 1st. Over the long term, the new tax was expected to result in reduced production as the resultant disincentive to explore reduces the number of new discoveries being made.

The State of Western Australia was again the nation's dominant gold-producing State. Australia's two largest gold mines, Boddington and Telfer, were in Western Australia. Production at Boddington, the nation's largest gold mine, amounted to about 12,400 kg (400,000 ounces). During the year, a new \$15 million mill circuit to recover gold and copper from the mine's supergene ore reserves was completed. The new circuit raises the productive

capacity of the mine, 97 km (60 miles) southeast of Perth, by almost 10%. Boddington was managed by the Worsley joint venture, 40%-held by Reynolds Metals Co. Reynolds also retained a 50% interest in the Mount Gibson gold mine, 300 km (186 miles) north of Perth. Mount Gibson produces about 2,643 kg (85,000 ounces) of gold annually. During the year, Reynolds also acquired another gold mining company, Mawson Pacific Ltd., which has mining operations in Western Australia at Southern Cross and Marvel Loch.

With an annual gold production of about 8,080 kg (260,000 ounces), the nation and the State's second largest gold mine is the Telfer Mine near Nullagine, previously operated by Newmont Australia Ltd. During 1991, Newmont and BHP Gold Mines Ltd. merged their gold mining interests to form a new company, now among Australia's largest gold producers, called Newcrest Mining Ltd. BHP retained a 23% interest in Newcrest. The new company has interests in seven operating or developing Australian gold mines, including Boddington, Telfer, Browns Creek, London Victoria, Ore Banda, Tuckabianna, and New Celebration.

Western Mining Corp. (WMC) owned or managed gold mines in Australia that produced 27,956 kg (898,895 ounces) during the fiscal year ending in June 1991. WMC's largest gold operation, its wholly owned Kambalda Gold Operations with several mines in the Kambalda area, produced 9,145 kg (294,063 ounces), a 45% increase over that of the previous year. Other WMC gold interests in Western Australia included multiple mine operations near the towns of Mount Magnet, Leinster, Lancefield, Norseman, and Kagloorlie. In the Leinster area, WMC's Redeemer underground mine started full-scale production using two computer-controlled production drill rigs. WMC also has gold mining interests in the Australian States of Queensland, South Australia, the Northern Territory, and Victoria, as well as overseas.

Also in Western Australia, Placer Pacific Ltd. and its partner, AMC Gold Ltd., decided in early 1991 not to

proceed with a previously announced underground development plan at the Big Bell Mine near Cue. During 1991, Big Bell produced a record 4,223 kg (135,800 ounces). Production at Placer Pacific's 45.4%-held Granny Smith Mine, near Laverton, amounted to almost 6,282 kg (202,000 ounces). Granny Smith completed its first full year of production in May. Placer also held a 70% interest in the Kidston Mine west of Townsville in the State of Queensland. Kidston, Queensland's largest gold mine, produced 5,964 kg (191,753 ounces) during 1991. Along Kalgoorlie's famous Golden Mile, Homestake Gold of Australia Ltd. and its partner, Gold Mines of Kalgoorlie Ltd., produced 7,251 kg (233,160 ounces) at their gold operations, which consist of four mines (two open pit and two underground), five mills, and two roasters. The most important component of the Kalgoorlie operations was the Super Pit, one of the largest open pit mines in Australia. The partner's principal underground mine was the Mount Charlotte Mine near the city center.

In central New South Wales, CRA Ltd. moved closer to its planned mid-1992 startup at the Peak Mine, in the Cobar District. The new underground operation was expected to produce 3,110 kg (100,000 ounces) of gold together with copper, zinc, and lead. In the State of Victoria, a new mining act was reportedly passed into law in November. The new law reportedly was designed to foster and encourage the mining industry in Victoria, which has a long history of gold mining. In April, Brunswick NL poured the first bar of production gold at its New Fosterville Mine, 20 km (12 Miles) east of Bendigo, Victoria. Work was later halted at the mine but may resume in 1992. Other Australian gold mines reportedly beginning production during the year included the Tick Hill Mine of Carpentaria Gold in Queensland, the Tindals Mine of Tindals Gold Mines NL, Aquarius Exploration NL's Penny West Mine in Western Australia, and Dominion Mining Ltd.'s Woolwonga Mine in the Northern Territory.

The Government of Australia announced in June that mining would not be permitted at the Coronation Hill precious-metals deposit in the Northern Territory and that the deposit area will be incorporated within the Kakadu National Park. In 1989, responding to mounting opposition by conservationists following the 1985 discovery of the deposit, the Government stopped work on the project pending completion of a study commission report. The principal opposition to the project came from local aborigines who reportedly claimed that the Spirit Bula, which they believed resided in the hill, will bring sickness and destruction if disturbed. The Aborigines reportedly had not lived on the land for more than 60 years, and part of the area around Coronation Hill had previously hosted uranium mining and exploration activities. The three companies involved in discovering and evaluating the large gold, platinum, and palladium deposit at Coronation Hill had reportedly spent more than \$A15 million on exploration, engineering, and a feasibility study. Reserves of more than 31 metric tons (1 million ounces) of gold plus 5% platinum and palladium in the ores reportedly had been established prior to the stop-work order.

On March 7, GoldCorp Australia, operator of the Perth Mint in Western Australia, introduced three large gold bullion coins, one of which weighs 1 kg, or about 32 troy ounces, reportedly the world's largest legal tender coin of any type produced in this century. The largest gold coin ever minted was produced by the U.S. company Leach and Garner for the 1986 World Exposition in Vancouver, British Columbia, Canada. The 14-karat gold coin, valued at the time at \$1.2 million, weighed 165.3 kg.

Canada.—At the close of 1991 there were 60 primary gold mines operating in Canada, according to an annual review of Canadian gold developments prepared by the Canadian Department of Energy, Mines and Resources.¹⁴ Canada was again the world's fifth largest gold producer, following Australia.

With a total gold output of 77 metric tons (2.5 million ounces), Ontario remained the dominant gold-producing Province during 1991. Gold from the mines in the Hemlo area near Marathon, Ontario, accounted for more than 50% of Provincial production. The three Hemlo mines, all opened in 1985, were the Page-William Mine, the Golden Giant Mine, and the David Bell Mine. Only one mine was opened during 1991, the Cheminis Mine of Northfield Minerals Inc. and Towerland Properties, near Virginiatown, Ontario. The reopened underground operation was expected to produce at a rate of about 136,000 metric tons (150,000 short tons) of ore per year. In September, Corona Corp. and American Barrick closed their Renabie Mine near Wawa. Weak gold prices, declining reserves and grades at depth, and rising costs contributed to the closure. Several other Ontario mines, including the Bell Creek Mine, St. Andrew Goldfields' Mine, and one tailings reprocessing project, were also closed during the year.

Production in Canada's second largest gold-producing Province, Quebec, rose by 20% to 51.9 metric tons (1.67 million ounces) in 1991. The increase was attributed primarily to improved production at TVX Gold Inc.'s Casa Berardi Mine, 100 km (62 miles) north of LaSarre, and LAC Minerals' Bosquet No. 2 mine at Cadillac. Bosquet completed its first full year of production during 1991. In Bosquet Township, northwestern Quebec, Cambior Inc. entered commercial production on July 1 at its new wholly owned Mouska Mine. Production at the Mouska during the year amounted to 580 kg (18,647 ounces). Cambior held major interests in three other Quebec gold mines: the Doyon Mine, the new Silidor Mine, and the Pierre Beauchemin Mine. All are in the vicinity of Rouyn-Noranda, Quebec. Other mines beginning production in Quebec during 1991 included Agnico-Eagle Mines Ltd.'s Eagle West Mine near Joutel, the Norlartic Mine of Aur Resources Inc. and Nova-Cogesco Resources Inc., near Malartic, and the Simkar Mine of Renrico Explorations

Ltd. and Louvincourt Gold Mines Inc. east of Val d' Or. Several Quebec gold mines were closed owing to low metal prices.

Gold production from mines in the Yukon and Northwest Territories increased to 21.6 metric tons (696,774 ounces) in 1991. Low gold prices and higher operating costs forced Northgate Exploration Ltd. to place its Colomac Mine on care-and-maintenance status in June.

In November, Claude Resources, Inc. began gold production at its new Seabee Mine at Laonil Lake, 125 km (78 miles) northeast of La Ronge in the Province of Saskatchewan. The new underground mine was expected to produce about 1,500 kg (48,000 ounces) of gold per year from ore processed at an on-site, 400-ton-per-day carbon-in-pulp mill. Gold was first discovered at the Laonil Lake site in 1947, and the mine reportedly derives its name from the amphibious Seabee aircraft that serviced the property during subsequent summers of exploration. As at many other mining operations in northern Canada, two mining crews fly-in/fly-out on a 2-week rotational basis. Corona Corp. and International Mahogany Corp. depleted the ore reserves at their Jolu Mine 120 km (75 miles) northeast of La Ronge, Saskatchewan, then closed the mine.

British Columbia's gold production reached 18.7 metric tons (603,225 ounces) in 1991, a 16% increase over that of the previous year. Two new gold mines began production during the year: the Snip Mine of Cominco Ltd. and Prime Resources Group Inc. began in January, and Tenajon Resources Corp. and Westmin Resources Ltd.'s SB project northwest of Stewart in the Salmon River Valley began producing gold in June. Near yearend, Placer Dome Inc. terminated plans to jointly develop the rich Eskay Creek gold deposit with partner International Corona Corp. Exploration at Eskay Creek, in northern British Columbia, had outlined a gold reserve of more than 90 metric tons (2.9 million ounces).

Latin America.—Gold mine production in Latin America generally was little changed from that of the previous year.

In Brazil, gold production at 80 metric tons (2.6 million ounces) was 6% below that of 1990. Production by the nation's independent gold miners or "garimpeiros" was estimated to have declined about 15% during the year to about 47 metric tons (1.5 million ounces), while production from the regulated or formal sector increased from 30 metric tons (965,000 ounces) in 1990 to about 33 metric tons (1.1 million ounces) in 1991. Garimpeiros production had been declining for several years owing to weak gold prices, especially at the local level, declining ore grades, depletion of easily accessible alluvial deposits, and wet weather conditions. Increased Government enforcement of regulations pertaining to protection of the environment and the indigenous Indian populations, as well as illegal intrusions by garimpeiros on mineral land concessions held by companies in the formal sector, had also restricted activities in those areas affected. During 1991, there were an estimated 300,000 garimpeiros operating in Brazil. The Government of Brazil estimated that about one-half of the gold produced annually by the garimpeiros is smuggled out of Brazil from about 2,500 separate locations. In the State of Par , Brazil's State-owned mining company, Companhia Vale do Rio Doce (CVRD) reportedly began production in September at its new open pit Igarap  Bahia gold mine. The new mine, in the Carajas region, will treat 2,000 to 3,000 metric tons (2,200 to 3,300 short tons) of ore per day for an expected annual yield of 4 to 5 metric tons (130,000 to 160,000 ounces) of gold. The Igarap  Bahia Mine and the Fazenda Brasileiro Mine, which opened in 1985 in the State of Bahia, are CVRD's principal gold-producing operations. During the same month, CVRD's new open pit Maria Pr ta Mine in Bahia completed its first full year of operation. Near yearend, WMC Minera o Ltda. completed open pit mining at its 75%-held Jenipapo project west of Goi nia in the State of Goi s. About 270 km (165

miles) north of Goi nia, WMC continued open pit and heap-leaching operations at its Mara Rosa Mine. At Mara Rosa, the company expanded crushing capacity at the site to 200,000 metric tons (220,000 short tons) per year.

In Bolivia, the Kori Kollo Mine, near Oruro, Bolivia's largest gold mine, produced 1,555 kg (50,000 ounces) of gold using heap-leaching recovery methods. The mine also recovered 10.3 metric tons (331,000 ounces) of silver during 1991. Development work at the mine, owned and operated by Inti Raymi, an 85%-held affiliate of Battle Mountain Gold Co., was focused during 1991 on planning for the mining of a large mill-grade, gold-bearing sulfide deposit lying beneath the oxidized cap presently being mined. A number of overseas companies pursued gold in Bolivia during the year, including RTZ and Cominco Resources International Ltd. As in past years, suction dredging operations for placer gold by numerous small companies were active along the river channels of the Rio Beni, Rio Madre de Dios, and the Rio Madera in northern Bolivia and along the border with Brazil. In April, the Government of Bolivia revised its mining code. The new code has a number of provisions aimed at making Bolivia more attractive to foreign mining and exploration firms. New laws to encourage investment and mining were also enacted in several other Latin American nations, including Ecuador, Peru, and Venezuela.

Despite the recent heightened levels of gold mining and exploration activity in Chile, mine production was essentially the same as that of the previous year. Chile's leading gold-producing mine, El Indio, 83%-held by LAC Minerals, produced almost 600 kg (191,342 ounces) or 11% less than that in 1990. Production at the mine and the nearby Tambo Mine, high in the Andes near the Argentinian border, was affected by a number of factors during 1991, including lower ore grades and recoveries plus a 26-day labor strike. El Indio also produced 43.3 metric tons (1.4 million ounces) of silver and almost 30,000 metric tons of copper. In the Maricunga

District of central Chile, a prolonged startup of a new treatment plant resulted in lower-than-expected output at Placer Dome's 50%-held LaCoipa Mine. The new plant was fully operational by yearend, and gold production for the year amounted to 2,173 kg (70,000 ounces) or more than twice the previous year's output. North of LaCoipa in the same district, Homestake's wholly owned El Hueso Mine continued to be plagued by low metal prices, low ore grades, and the inability of the mine to expand proven ore reserves. Because of the low grades and slightly lower mining rate, gold production fell by 10% to 2,033 kg (65,356 ounces). Heap-leaching operations began during the first quarter at the San Cristobal Mine in the Atacama desert of northern Chile. The first gold was recovered in midyear. Battle Mountain Gold Co. owns a 56.52 interest in the mine through its affiliate, Niugini Mining Ltd. Startup problems at the mine resulted in 435 kg (14,000 ounces) less in production than the targeted 1,100 kg (35,000 ounces). San Cristobal was scheduled to produce more than 2,000 kg (65,000 ounces) in 1992. Following several years of high costs and operating difficulties at Anglo American's 56%-held Marte heap-leaching project, operations were suspended in September. Several Chilean gold projects were in an advanced stage of exploration during 1991, including Bema Gold Corp.'s Refugio Project and Dayton Mining Corp.'s Andocollo Project. Planned annual production rates for the two properties were 7,240 kg (233,000 ounces) and 3,400 kg (110,000 ounces), respectively.

In Colombia, Latin America's second largest gold-producing nation, Greenstone Resources Ltd., completed its first full year of production in November at its Oronorte Mine, in the Department of Antioquia, 250 km (155 miles) north of Bogotá. The newly reopened underground operation, discovered in 1939 and mined on a small-scale until 1946, has an annual production capacity of about 780 kg (25,000 ounces) of gold. Greenstone also had gold exploration interests in Costa Rica and at the Santa

Rosa project in Panama. Elsewhere in Antioquia, which produces 70% of the nation's gold, the drug war and guerrilla activity reportedly continued to pose security problems for mining and exploration companies.

Gold production at the Pueblo Viejo Mine in the Dominican Republic, that nation's sole gold producer, continued to decline. The lower production reflected the rapidly nearing depletion of the mine's oxide ore reserves. The Government of the Dominican Republic has established a commission consisting of the directors of the state-owned mining company, Rosario Dominicana S.A., and a group of advisors to determine ways to develop the mine's vast gold-bearing sulfide ores.

Near Magdalena, in Mexico's State of Sonora, Phelps Dodge Corp. and its partner, the Ariztequé Group, a private Mexican consortium, began production at the new Santa Gertrudis Mine. The open pit and heap-leaching facility, opened in late November, was designed to produce more than 1,560 kg (50,000 ounces) of gold per year. The most important development for gold in Mexico during 1991 was the interest shown by both Mexican and foreign mining companies in exploring for gold in Sonora, Baja California, and Sinaloa. Many of the companies with demonstrated interest in Mexico during 1991 were from the United States and Canada.

In Peru, a number of lode and placer mines continued operation during the year despite serious national economic and social difficulties and continuing terrorist activity that forced companies operating in the Central Mining District to make large investments in security measures. Following 6 years of exploration at the Yanacocha gold project, 20 km (12 miles) north of Cajamarca in northern Peru, Compañía Minera Yanacocha S.A. formed a mining consortium owned 40% by Newmont Mining and 60% by Peruvian and French interests. The company plans to start production by 1985 at a rate of 15.5 metric tons (500,000 ounces) per year. The investment required to develop the mine will reportedly be the first important

foreign investment in Peru's mineral sector in almost 20 years. The Yanacocha deposit is reportedly the first disseminated-type gold deposit discovered in Peru. In March, the Government of Peru authorized the purchase, sale, export, import, and private ownership of gold. The authorization included raw, refined, and semimanufactured gold. Previously, Banco Minero and the Central Reserve Bank were the only legal markets for domestic gold production.

Oceania.—Gold production in Papua New Guinea increased 96% over production achieved during the previous year. This large increase generally reflects the first full year of production at Placer Pacific Ltd.'s New Porgera Mine, in the highlands of Enga Province. The full year's production at Porgera was 37.8 metric tons (1,216,100 ounces), which was 43% more than initially projected owing to higher mill throughput and recoveries. Production was expected to increase further in 1992 with the mining of high-grade underground ore and the processing, by pressure oxidation, of stored residue material containing refractory gold. In the same Province, about 18 km (12 miles) southwest of Porgera, CRA completed its first full year of operation at its new Mount Kare alluvial project. Production during 1991 was reportedly a disappointing 282 kg (9,100 ounces). Operations were suspended following an armed attack on the mine in early 1991.

CRA also continued exploration and drilling at its Hidden Valley Project about 200 km (125 miles) southeast of Mount Kare. Misima Island Mines Pty. Ltd. produced about 10 metric tons (323,127 ounces) of gold during its second full year of production at the new Misima Mine in Milne Bay Province.

At Mount Fulbian in the far west of Enga Province, the OK Tedi copper-gold mine yielded 13.2 metric tons (426,034 ounces) of gold, down about 4% from that of 1990. Copper production, however, increased 24% during the same period. CRA's 53.6%-held Bougainville Mine remained closed during 1991. The

mine was closed in May 1989 owing to a political dispute.

The partners in the development of the giant Lihir Island gold deposit, RTZ Corp. and Niugini Mining Ltd., were under pressure from the Government of Papua New Guinea during the year to speed up development of the property. The property is on a small island off the east coast of the island of New Ireland.

In late 1991, Papua New Guinea's only precious-metals refiner, Metal Refining Operations, reportedly made its first shipment of refined 1-kg gold bullion bars directly to the international market in Hong Kong. The shipment, valued at about \$400,000, marked the first time in almost 100 years of gold mining in Papua New Guinea that gold has been sent directly to the international market in final refined form. Previously, gold from Papua New Guinea was refined elsewhere and entered the world market bearing the stamps and certification marks of overseas refineries.

Exploration for gold in the Southwest Pacific continued at a brisk pace. Law and order problems in Papua New Guinea, particularly in some highlands Provinces, continued to plague exploration, mining, and petroleum companies alike.

The only gold mine currently in operation in Fiji, the Emperor Mine in Vatukoula, first began gold and silver production in 1935. In January, Western Mining Corp. sold its interest in the property to Emperor Gold Mines Ltd. Gold was produced in 1991 from both surface and underground sources; however, a year-long labor dispute and low world gold prices resulted in a decline in production during the year.

A report was published describing the gold deposits and the excellent gold potential of the entire region of the Outer Melanesian arc system in the Southwest Pacific.¹⁵ The report covers northern Papua New Guinea, the Solomon Islands, Vanuatu, and Fiji, an area where 22 major gold deposits have so far been identified.

In January, Freeport Indonesia completed its first full year of mining copper-gold-silver ore at its recently

discovered Grasburg deposit in West Irian, on the Indonesian side of the island of New Guinea. Grasburg, adjacent to Freeport's older Ertsburg Mine, reportedly possesses the largest published gold reserves of any single operating mine in the world.

Grasburg's major contribution to Indonesia's total production was reflected in a 51% increase over that of the previous year. In the Province of East Kalimantan, CRA began commissioning work at its 90%-held Kelian gold mine. The first metal was poured in January 1992. In addition, one-half dozen or more State-owned and private companies were mining gold in Indonesia during 1991. Indonesia's Department of Mines and Energy reported that there were also as many as 30,000 illegal miners operating in Kalimantan, Sulawesi, Sumatra, and Java during 1991. The undocumented gold from these small operations has traditionally been refined and processed for local consumption by village jewelers or smuggled outside the country. Government officials speculated that gold production by illegal miners might average as much as 1 gram (0.03 ounce) per miner per day. If so, the total of illegally mined gold would be roughly 9,300 kg (300,000 ounces) per year. Small-scale gold mining has reportedly been conducted in Indonesia for thousands of years.

The 43% increase in New Zealand's 1991 production was mostly attributable to the first full year's contribution of gold from the new Macraes Mine, in the Otago region of New Zealand's South Island. In December, Cyprus Gold (NZ) Ltd. poured its first gold at its new Golden Cross Mine 8 km (5 miles) northwest of Waihi in the Hauraki Goldfield on the North Island. At full capacity, Golden Cross is expected to produce about 3,300 kg (106,000 ounces) annually for about 8 years. A report was published detailing the geology and mineral resources of New Zealand.¹⁶ New Zealand's gold-producing districts and the lode and placer mines and prospects are described.

U.S.S.R.—In late 1991, tentative statistical data on the performance of the Soviet gold industry began to emerge. Since 1926, all matters pertaining to gold had been classified as state secrets, even to the inner circles of the Government. In late November, the Russian Ministry of Finance released statistics on gold production, consumption, bullion reserves, and exports covering 1953 and 1984 through estimated 1991, thereby ending years of speculation by Western analysts, at least for the periods covered in the disclosure. The official mine production data for 1953, for example, demonstrated that actual 1953 mine production at 117 metric tons (3.8 million ounces) was substantially below estimates prepared by Western observers, including the U.S. Bureau of Mines. Estimates by the Bureau for gold mine production during the period 1984 through 1990 were essentially in line with the official data released by the Soviets.

The size of the Soviet bullion reserves had long been a source of speculation and controversy outside of the U.S.S.R. To many Western market analysts, the large quantity of marketable Soviet bullion generally thought to exist was seen to overshadow the world gold market. Despite the Russians' reputation as astute gold traders not inclined toward product dumping, sudden heavy Soviet sales to earn foreign exchange credits could, if improperly executed, seriously disrupt the world market. Prior to the release of official reserve data in November, there was a flurry of renewed speculation regarding the size of the reserves, their possible role in the Soviet monetary system, implications of a large reserve for the western market, world prices, etc. This speculation ceased when the official data were released, indicating that by 1991 only 240 metric tons (7.7 million ounces) remained in reserve compared with 2,050 metric tons (66 million ounces) held in 1953.

Information on the distribution of mine production in the U.S.S.R. was also released. About 60% of the U.S.S.R.'s gold production is reportedly derived from gold mines in Russia, with about 90% of that fraction deriving from placer

mines mostly in the Northeast region. The only other Republics of note are Uzbekistan, with almost 30% of the National total, and Armenia and Kazaksstan, with about 5% each.

At the end of 1991, Glavalmazoloto of the U.S.S.R., the State Ministry presiding over all mining, refining, and manufacturing operations relating to precious metals, was taken over by Russia and renamed Rosalmazoloto (the Russian word for gold is "zoloto"). Following long-established practice, raw gold is delivered from the mines to state offices in Moscow for distribution to refineries in Moscow, Priosky, and elsewhere. The refined production is then directed to manufacturers and reserve depositories.

Throughout the year there was considerable cautious interest on the part of U.S. and other companies regarding the apparent opportunities opening up for joint participation in Soviet gold mining. Some companies were able, by yearend, to establish tentative ties with emerging Russian businesses. By yearend, however, many questions remained to be answered before foreign companies could proceed to establish firm, workable relationships. There was uncertainty regarding the status of existing mining laws, permitting procedures and legitimate lines of authority, disposition and repatriation of profits, regulations regarding foreign participation and partnerships, etc. The answers to most of these problems were, like the Commonwealth of Independent States itself, evolving as the new year arrived. (See table 15.)

Current Research.—The U.S. Bureau of Mines maintains nine research centers throughout the Nation, and most conduct research into various aspects of mining and extractive metallurgy that may be directly or indirectly beneficial to the gold mining industry.¹⁷ Because gold mining is pursued in many nations, the results of this ongoing work may, like the Bureau's earlier work in heap leaching, ultimately benefit a broad segment of the industry worldwide. In 1991, the Bureau's research relating to gold mining

generally focused on the use of cyanide in the recovery process. The Bureau addressed several questions regarding the use of cyanide, including such topics as the mass balance of cyanide in the leaching process, the mobility of metals in the heap during heap leaching, the persistence of cyanide in the environment, alternatives to cyanide, and reclamation of mining sites where cyanide was employed. The Bureau was also investigating the leaching of metals from very low-grade ores using biotechnology. Bioleaching research for precious-metals focused on a preleach treatment of precious-metal-bearing sulfide ores.

OUTLOOK

Gold is an internationally traded commodity but, unlike most commodities bound by the traditional laws of market supply and demand, gold also serves as a substance of wealth, a storehouse of value, held by investors and Governments alike.

Preparation of an outlook for normal supply and demand may first require consideration of the outlook for prices. Although the price of gold generally defies forecasting, consideration of the forces at work in the marketplace may aid in establishing the direction that the price may take. GFMS as well as other market observers generally avoid forecasts for the gold price for more than the near term. In its annual review,¹⁸ GFMS emphasizes that future gold prices will be greatly influenced by two principal factors: future gold supply developments resulting from the breakup of the U.S.S.R. and the degree to which, in these uncertain times, gold will continue to be absorbed globally in jewelry, industrial, and investment applications. GFMS acknowledges that Western World mine production would probably decline sharply if the prices seen in early 1992 were to remain unchanged and that it has only been the miner's inherent optimism that has kept some marginal mines open under today's prices.

The demand for jewelry and to some extent consumer electronic products is greatly influenced by consumer

confidence in the economic future. A sustained economic recovery would instill confidence and lead to greater demand for gold-bearing products and higher gold prices. Similarly, the degree to which gold would be taken in or released from private or official investors' vaults is likewise dependent upon regional investor attitudes, Government policies, and markets.

The outlook for gold is aptly summarized by the GFMS¹⁸ review that concludes that robust world gold price recovery could occur under two very different scenarios. One involves a return to strong economic growth accompanied by a rapid increase in jewelry demand or, at the other extreme, a massive asset deflation that would cause a flight to gold. According to GFMS, "...Between these two extremes, however, it is possible to imagine that, with a relatively mundane rate of economic growth, the physical market will not tighten fast enough to give much encouragement to gold holders who could thus continue as net sellers and maintain a depressed gold price for some time to come."

¹Ounce refers to troy ounce. One kilogram of gold weighs 32.1507 troy ounces.

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TABLE 1
SALIENT GOLD STATISTICS

		1987	1988	1989	1990	1991
United States:						
Mine production	kilograms	153,870	200,914	\$265,731	*294,527	\$289,885
Value in dollars per troy ounce		\$2,216,026	\$2,831,281	\$2,831,281	\$3,649,914	\$3,213,874
Percentage derived from:						
Precious-metal ores		91	W	W	W	W
Base-metal ores		6	W	W	W	W
Placers		3	2	2	1	1
Refinery production:						
Domestic and foreign ores	kilograms	112,368	137,829	183,685	204,856	183,317
Secondary (old scrap)	do.	63,843	52,784	37,144	*30,199	31,966
Exports:						
Refined	do.	71,177	271,335	123,599	140,923	174,377
Other	do.	48,453	56,902	87,492	155,474	109,750
Imports for consumption:						
Refined	do.	75,365	57,590	96,967	64,755	147,491
Other	do.	44,174	34,867	55,537	32,764	31,257
Gold contained in imported coins ¹	do.	33,716	² 17,947	² 13,218	² 8,429	² 3,514
Net deliveries from foreign stocks in Federal Reserve Bank	do.	95,146	208,277	132,231	51,464	61,595
Stocks, Dec. 31:						
Industry ³	do.	23,390	38,360	30,462	*37,065	39,411
Futures exchange ⁴	do.	81,647	44,634	69,727	50,881	49,893
Volume of U.S. Gold Futures Trading ⁵	metric tons	33,100	29,920	31,065	30,260	21,200
Department of the Treasury: ⁶						
American Eagle gold coin ⁷	kilograms	82,704	17,416	16,544	17,397	13,713
Other Numismatic gold coins	do.	—	8,626	1,349	695	952
Consumption in industry and the arts	do.	113,319	111,836	115,078	*118,065	114,354
Price: ⁸ Average per troy ounce		\$447.95	\$438.31	\$382.58	*\$384.93	\$363.29
Employment ⁹		11,100	13,100	15,100	*16,100	15,100
World:						
Production, mine	kilogram	*1,660,535	*1,848,448	*2,023,050	*2,127,398	*2,111,522
Official reserves ¹⁰	metric tons	*35,655	*35,829	*35,655	*35,623	35,551

¹Estimated. ²Revised. W Withheld to avoid disclosing company proprietary data.

³Calculated by the Gold Institute from reports by the Bureau of the Census.

⁴Beginning 1988 net imports (exports).

⁵Unfabricated refined gold held by refiners, fabricators, dealers, and U.S. Department of Defense.

⁶Commodity Exchange Inc. only. Stocks held by other exchanges estimated to be less than 2% of totals shown.

⁷Exchanges: Commodity Exchanges Inc., Chicago Board of Trade International Monetary Market (1987-88 only), and Mid-America Commodity Exchange.

⁸Sales to market fiscal year 1987-90. Fiscal year begins Oct. 1, of previous year indicated. Gold bullion disbursements to U.S. Mint coin programs fiscal 1991.

⁹Sales program began Oct. 20, 1986.

¹⁰Engelhard Industries quotation.

¹¹Mine Safety and Health Administration.

¹²Held by market economy country central banks and governments and international monetary organizations. Source: International Monetary Fund.

TABLE 2
MINE PRODUCTION OF GOLD IN THE UNITED STATES, BY STATE

(Kilograms)

State	1987	1988	1989	1990	1991
Alaska ¹	3,812	4,210	5,756	3,232	3,196
Arizona	1,791	4,549	2,768	5,000	2,068
California	18,277	22,442	29,804	29,607	29,873
Colorado	5,561	5,126	3,448	² 2,357	3,181
Idaho	3,041	³ 3,218	3,057	W	3,348
Michigan	W	W	W	—	—
Montana	7,143	9,175	12,434	13,012	18,511
Nevada	83,342	114,322	153,995	¹ 179,078	177,312
New Mexico	W	W	1,076	888	W
Oregon	W	W	W	W	—
South Carolina	W	W	W	W	W
South Dakota	W	13,981	16,123	¹ 17,870	16,371
Utah	W	W	W	W	W
Washington	W	W	W	9,620	9,954
Total	153,870	200,914	265,731	²294,527	289,885

¹Revised. W Withheld to avoid disclosing company proprietary data; included in "Total."

²These figures, reported to the U.S. Bureau of Mines, probably understate production. Data collected by the State indicate production to have been as follows, in kilograms: 1987—7,154; 1988—8,258; 1989—8,852; 1990—7,206; and 1991—7,585.

TABLE 3
TWENTY-FIVE LEADING GOLD-PRODUCING MINES IN THE UNITED STATES IN 1991, IN ORDER OF OUTPUT

Rank	Mine	County and State	Operator	Source of gold
1	Carlin Mines Complex	Eureka, NV	Newmont Gold Co.	Gold ore.
2	Goldstrike	do.	Barrick Goldstrike Mines Inc.	Do.
3	Bingham Canyon	Salt Lake, UT	Kennecott-Utah Copper Corp.	Copper ore.
4	Jerritt Canyon (Enfield Bell)	Elko, NV	Independence Mining Co. Inc.	Gold ore.
5	Smokey Valley Common Operation	Nye, NV	Round Mountain Gold Corp.	Do.
6	Homestake	Lawrence, SD	Homestake Mining Co.	Do.
7	McCoy and Cove	Lander, NV	Echo Bay Mining Co.	Do.
8	McLaughlin	Napa, CA	Homestake Mining Co.	Do.
9	Chimney Creek	Humboldt, NV	Goldfields Mining Corp.	Do.
10	Fortitude and Surprise	Lander, NV	Battle Mountain Gold Co.	Do.
11	Bullfrog	Nye, NV	Bond Gold Bullfrog Inc.	Do.
12	Mesquite	Imperial, CA	Goldfields Mining Corp.	Do.
13	Getchell	Humboldt, NV	FMG Inc.	Do.
14	Sleeper	do.	Nevada Gold Mining Inc.	Do.
15	Cannon	Chelan, WA	Asamera Minerals (U.S.) Inc.	Do.
16	Ridgeway	Fairfield, SC	Ridgeway Mining Co.	Do.
17	Jamestown	Tuolumne, CA	Sonora Mining Corp.	Do.
18	Paradise Peak	Nye, NV	FMC Gold Co.	Do.
19	Rabbit Creek	Humboldt, NV	Rabbit Creek Mining Inc.	Do.
20	Barney's Canyon	Salt Lake, UT	Kennecott Corp.	Do.
21	Zortman-Landusky	Phillips, MT	Pegasus Gold Inc.	Do.
22	Golden Sunlight	Jefferson, MT	Golden Sunlight Mines Inc.	Do.
23	Wind Mountain	Washoe, NV	Amax Gold Inc.	Do.
24	Foley Ridge & Annie Creek	Lawrence, SD	Wharf Resources	Do.
25	Kettle River	Ferry, WA	Crown Resources Corp.	Do.

TABLE 4
GOLD PRODUCED IN THE UNITED STATES, BY STATE, TYPE OF MINE,
AND CLASS OF ORE

Year and State	Placer (kilo-grams of gold)	Lode					
		Gold ore		Gold-silver ore		Silver ore	
		Metric tons	Kilograms of gold	Metric tons	Kilograms of gold	Metric tons	Kilograms of gold
1987	5,082	84,195,951	137,832	W	W	7,944,696	1,235
1988	4,754	127,883,933	181,891	W	W	9,573,505	2,075
1989	5,711	169,380,297	236,207	W	W	4,450,703	505
1990	2,579	200,080,467	272,268	W	W	W	W
1991:							
Alaska	W	—	—	—	—	—	—
Arizona	W	1,360,973	474	—	—	—	—
California	W	W	W	—	—	—	—
Colorado	—	W	W	—	—	—	—
Idaho	—	1,996,561	W	—	—	W	W
Montana	W	W	12,550	—	—	—	—
Nevada	W	136,031,679	174,519	—	—	W	W
New Mexico	—	W	W	—	—	—	—
South Carolina	—	W	W	—	—	—	—
South Dakota	W	8,729,704	W	—	—	—	—
Utah	—	6,816,545	6,273	—	—	—	—
Washington	—	W	9,954	—	—	—	—
Total	2,888	203,694,888	260,196	—	—	W	W
Percent of total gold	1	XX	90	XX	—	XX	W

	Lode					
	Copper ore		Other ¹		Total	
	Metric tons	Kilograms of gold	Metric tons	Kilograms of gold	Metric tons	Kilograms of gold
1987	165,407,018	8,074	W	W	258,668,990	153,870
1988	201,893,222	11,314	W	W	340,614,832	200,914
1989	210,474,747	17,620	W	W	391,059,545	265,731
1990	156,177,067	W	W	W	363,581,387	294,527
1991:						
Alaska	—	—	W	W	W	3,196
Arizona	108,264,908	1,594	—	—	109,625,881	2,068
California	W	W	—	—	21,737,574	29,873
Colorado	—	—	W	W	2,347,744	3,181
Idaho	—	—	W	W	2,336,494	3,348
Montana	W	W	W	W	41,592,664	18,511
Nevada	W	W	30	14	140,169,291	177,312
New Mexico	W	W	—	—	W	W
South Carolina	—	—	—	—	W	W
South Dakota	—	—	—	—	8,729,704	16,371
Utah	W	W	—	—	W	W
Washington	—	—	—	—	W	9,954
Total	196,489,385	W	W	W	409,018,221	289,885
Percent of total gold	XX	W	XX	W	XX	100

¹Revised. W Withheld to avoid disclosing company proprietary data; included in "Total." XX Not applicable.
²Includes lead, zinc, copper-lead, lead-zinc, copper-zinc, copper-lead-zinc ores, and old tailings, etc.

TABLE 5
LODE GOLD PRODUCED IN THE UNITED STATES, BY STATE

Year and State	Amalgamation		Cyanidation		Smelting of concentrates			Smelting of ore		Total gold recovered ¹ (metric tons)	Total gold recovered (kilograms)
	Ore treated (metric tons)	Gold recovered (kilograms)	Ore treated (metric tons)	Gold recovered (kilograms)	Ore concentrated (metric tons)	Concentrates smelted (metric tons)	Gold recovered (kilograms)	Ore smelted (metric tons)	Gold recovered (kilograms)		
1987	W	W	88,696,450	129,812	169,472,280	3,430,726	17,548	W	W	58,668,990	2148,788
1988	W	W	133,042,143	173,493	207,228,838	3,969,256	21,057	W	W	340,614,832	2196,161
1989	W	W	172,294,506	228,040	189,266,803	3,827,109	30,283	W	W	391,059,545	2260,021
1990	W	W	199,644,031	264,833	163,749,630	3,649,072	25,828	W	W	363,581,387	2291,949
1991:											
Alaska	—	—	—	W	W	W	W	—	—	W	W
Arizona	—	—	1,350,509	363	108,261,506	2,008,680	1,579	13,866	126	109,625,881	2,068
California	W	W	21,259,553	26,461	W	W	W	—	—	21,737,574	229,873
Colorado	W	W	W	W	W	W	W	—	—	2,347,744	3,181
Idaho	—	—	1,996,561	W	W	W	W	—	—	W	3,348
Montana	W	W	W	W	22,364,638	251,984	W	—	—	41,592,664	218,511
Nevada	124,015	100	140,013,770	176,758	—	—	W	W	W	140,169,291	2177,312
New Mexico	—	—	—	—	W	W	W	W	W	W	W
South Carolina	—	—	W	W	—	—	—	—	—	W	W
South Dakota	—	—	8,729,704	W	—	—	—	—	—	8,729,704	216,371
Utah	—	—	6,779,706	6,048	W	W	W	W	W	W	W
Washington	—	—	W	W	488,763	24,774	W	—	—	W	9,954
Total	W	W	206,609,769	256,163	201,369,753	3,907,816	28,296	W	W	409,018,221	286,998

¹Revised. W Withheld to avoid disclosing company proprietary data; included in "Total," where applicable.

²Includes old tailings and some nongold-bearing ores not separable, in amounts ranging from 0.15% to 0.25% of the totals for the year listed.

³Includes some placer production to avoid disclosing company proprietary data.

TABLE 6
GOLD PRODUCED IN THE UNITED STATES BY CYANIDATION¹

Year	Extraction in vats, tanks, and closed containers ²		Leaching in open heaps or dumps ³	
	Ore treated (metric tons)	Gold recovered ⁴ (kilograms)	Ore treated (metric tons)	Gold recovered (kilograms)
1987	'29,228,356	74,807	'59,468,094	55,005
1988	'30,779,239	100,817	'102,262,904	72,676
1989	'42,464,260	121,716	'129,830,246	106,324
1990	49,688,230	'135,764	149,955,801	'129,069
1991	61,168,407	161,699	145,441,362	94,464

¹Revised.

²May include small quantities recovered by leaching with thioourea, by bioextraction, and by proprietary processes.

³Including autoclaves.

⁴May include tailings and waste ore dumps.

⁵May include small quantities recovered by gravity methods.

TABLE 7
**GOLD PRODUCED AT PLACER MINES IN THE UNITED STATES,
 BY METHOD OF RECOVERY¹**

Method of recovery	Mines producing	Washing plants	Material washed ² (thousand cubic meters)	Gold recoverable		
				Quantity (kilograms)	Value (thousands)	Average value per cubic meter
Bucketline dredging:						
1987	4	5	7,136	3,471	\$49,989	\$7.006
1988	3	4	5,775	2,590	36,497	6.320
1989	3	4	5,560	2,720	33,454	6.016
1990	4	4	3,454	1,528	18,913	5.476
1991	3	4	4,949	1,400	16,352	3.304
Dragline dredging:						
1987	3	3	71	367	971	8.190
1988	—	—	—	—	—	—
1989	—	—	—	—	—	—
1990	—	—	—	—	—	—
1991	—	—	—	—	—	—
Nonfloating washing plants:						
1987	6	6	636	465	6,698	10.526
1988	6	6	473	302	4,255	9.004
1989	4	4	72	92	1,134	15.851
1990	—	—	—	—	—	—
1991	2	2	3	14	166	54.288
Underground placer, small-scale mechanical and hand methods, suction dredge:³						
1987	15	15	367	1,078	15,529	42.330
1988	13	13	838	1,862	26,225	31.292
1989	20	20	1,404	2,899	35,654	25.349
1990	21	21	1,043	1,050	12,999	12.414
1991	14	14	559	1,474	17,211	30.763
Total placers:⁶						
1987	28	29	8,210	5,082	73,187	8.867
1988	22	23	7,085	4,754	66,977	9.453
1989	27	28	7,036	5,711	70,242	9.975
1990	25	25	4,497	2,579	31,912	7.086
1991	19	20	5,511	2,888	33,729	6.118

¹Revised.

²Data are only for those mines that report annually on the U.S. Bureau of Mines voluntary survey; there are many more, usually smaller and less well-established operations, mainly in Alaska, that do not report.

³Excludes tonnage of material treated at commercial sand and gravel operations recovering byproduct gold.

⁴Includes gold recovered at commercial sand and gravel operations.

⁵Gold recovered as a byproduct at sand and gravel operations not used in calculating average value per cubic meter.

⁶May include hydraulicking.

⁷Data may not add to totals shown because of independent rounding.

TABLE 8
U.S. REFINERY PRODUCTION OF GOLD¹

(Kilograms)

Raw material	1987	1988	1989	1990	1991
Concentrates and ores:					
Domestic and foreign	112,368	137,829	183,685	204,856	183,317
Old scrap	63,843	52,784	37,144	¹ 30,199	31,966
New scrap	45,166	80,702	127,086	¹ 141,178	177,495
Total ²	221,376	271,315	347,915	³ 376,232	392,779

¹Revised.

²Data may include estimates.

³Data may not add to totals shown because of independent rounding.

TABLE 9
U.S. CONSUMPTION OF GOLD,¹ BY END-USE SECTOR²

(Kilograms)

End use	1987	1988	1989	1990	1991
Jewelry and the arts:					
Karat gold	58,635	57,959	60,877	¹ 69,801	79,875
Fine gold for electroplating	3,133	1,469	1,283	429	373
Gold-filled and other	9,256	7,598	7,364	8,132	3,819
Total ³	71,024	67,027	69,524	¹ 78,362	84,067
Dental	6,944	7,576	7,927	8,700	8,485
Industrial:					
Karat gold	1,892	1,104	1,215	1,020	1,068
Fine gold for electroplating	12,343	15,088	20,684	17,251	12,624
Gold-filled and other	21,010	21,034	15,723	12,725	8,110
Total ³	35,245	37,226	37,621	30,996	21,802
Small items for investment ⁴	106	7	7	7	—
Grand total ³	113,319	111,836	115,078	¹ 118,065	114,354

¹Revised.

²Gold consumed in fabricated products only; does not include monetary bullion.

³Data may include estimates.

⁴Data may not add to totals shown because of independent rounding.

⁵Fabricated bars, medallions, coins, etc.

TABLE 10
YEAREND STOCKS OF REFINED GOLD IN THE UNITED STATES

(Kilograms)

	1987	1988	1989	1990	1991
Industry	23,390	38,360	30,462	¹ 37,065	39,411
Futures exchange ¹	81,647	44,634	69,727	50,881	49,893
Department of the Treasury ²	8,160,251	¹ 8,145,696	¹ 8,147,169	¹ 8,146,432	8,145,696
Earmarked gold ³	10,252,982	¹ 10,045,646	¹ 9,913,040	¹ 9,862,208	9,800,325

¹Revised.

²Commodity Exchange Inc. only. Stocks held by other exchanges estimated to be less than 2% of totals shown.

³Includes gold in Exchange Stabilization Fund.

⁴Gold held for foreign and international official accounts at New York Federal Reserve Bank.

TABLE 11
U.S. GOLD PRICES¹

(Dollars per troy ounce)

Period	Low		High		Average
	Price	Date	Price	Date	
1987	391.51	Feb. 18	501.25	Dec. 14	447.95
1988	396.62	Sept. 26	485.37	Jan. 8 and 11	438.31
1989	357.00	Sept. 15	416.86	Dec. 11 and 12	382.58
1990	347.09	June 14	425.12	Feb. 7	384.93
1991:					
January	367.27	Jan. 31	404.34	Jan. 16	384.94
February	362.01	Feb. 6	371.28	Feb. 8	365.10
March	355.30	Mar. 27	369.78	Mar. 8	364.60
April	352.35	Apr. 29	365.27	Apr. 9	359.63
May	355.40	May 2 and 6	362.76	May 29	358.07
June	362.16	June 24	373.48	June 10	368.00
July	362.61	July 30	372.18	July 10	368.78
August	348.64	Aug. 30	364.67	Aug. 1	357.46
September	345.49	Sept. 13	356.15	Sept. 30	350.02
October	355.20	Oct. 1	365.07	Oct. 21	359.94
November	354.15	Nov. 8	370.38	Nov. 25	360.80
December	354.40	Dec. 30	371.98	Dec. 9	362.17
Year	345.49	Sept. 13	404.34	Jan. 16	363.29

¹Revised.

¹Engelhard Industries daily quotation.

Source: Metals Week.

TABLE 12
U.S. EXPORTS OF GOLD, BY COUNTRY^{1 2}

Year and country	Ores and concentrates ³		Wastes and scrap		Doré and precipitates		Refined bullion		Total ⁴	
	Quantity (kilo-grams)	Value (thou-sands)	Quantity (kilo-grams)	Value (thou-sands)	Quantity (kilo-grams)	Value (thou-sands)	Quantity (kilo-grams)	Value (thou-sands)	Quantity (kilo-grams)	Value (thou-sands)
1987	1,385	\$19,818	28,092	\$390,832	18,976	\$264,008	71,177	\$1,034,186	119,630	\$1,708,844
1988	1,384	18,449	35,709	492,840	19,809	265,051	271,335	3,882,757	328,237	4,659,098
1989	16	165	44,541	542,150	42,935	242,690	123,599	1,490,151	211,091	2,275,156
1990	328	3,721	66,943	729,150	88,203	413,980	140,923	1,719,470	296,397	2,866,320
1991:										
Belgium	5	50	2,517	28,869	1	7	1,991	23,200	4,509	52,076
Canada	—	—	25,416	200,437	14,425	136,639	5,677	68,771	45,523	405,897
France	—	—	22,840	268,551	3,847	45,360	1,177	13,525	27,865	327,437
Germany	—	—	1,504	17,067	3,297	32,593	508	6,012	5,310	55,677
Hong Kong	—	—	265	3,180	6,389	72,714	54,412	632,947	61,066	708,844
Italy	—	—	182	1,907	31	264	76	714	289	2,884
Japan	—	—	88	953	2,600	26,433	3,766	43,199	6,455	70,586
Korea, Republic of	4	36	9	94	—	—	395	4,623	408	4,756
Mexico	—	—	—	—	171	2,083	5,265	61,758	5,436	63,841
Singapore	—	—	—	—	—	—	5,319	62,009	5,319	62,009
Sweden	—	—	918	10,528	56	659	—	—	973	11,186
Switzerland	—	—	201	2,314	11,478	132,696	52,988	621,514	64,667	756,524
Taiwan	—	—	—	—	—	—	3,590	41,478	3,590	41,478
United Arab Emirates	—	—	—	—	—	—	250	2,920	250	2,920
United Kingdom	—	—	10,212	119,343	3,174	36,439	38,290	448,779	51,676	604,565
Other	(⁵)	11	52	505	68	375	669	7,403	790	8,282
Total ⁴	10	98	64,204	653,748	45,536	486,266	174,377	2,038,850	284,127	3,178,962

¹Because of the implementation of the Harmonized Tariff System in Jan. 1989, export data may not be comparable with previous years' data.

²Bullion also moves in both directions between U.S. markets and foreign stocks on deposit in the Federal Reserve Bank. Monetary gold excluded.

³Includes gold content of base metal ores, concentrates, and matte destined for refining.

⁴Data may not add to totals shown because of independent rounding.

⁵Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 13
U.S. IMPORTS FOR CONSUMPTION OF GOLD, BY COUNTRY^{1, 2}

Year and country	Ores and concentrates ³		Wastes and scrap		Dore and precipitates		Refined bullion		Total ⁴	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
1987	1,429	\$17,926	13,955	\$160,073	28,790	\$402,026	75,365	\$1,052,941	119,539	\$1,632,966
1988	2,621	34,141	6,468	79,483	25,778	355,763	57,590	799,901	92,457	1,269,288
1989	2,426	7,103	39,952	115,685	13,159	157,952	96,967	1,198,734	152,504	1,479,473
1990	5,346	8,355	23,173	206,975	4,245	50,635	64,755	795,007	97,519	1,060,971
1991:										
Argentina	—	—	—	—	—	—	153	1,719	153	1,719
Bolivia	—	—	274	1,760	—	—	5,477	62,127	5,751	63,887
Brazil	—	—	14	120	—	—	10,112	115,390	10,125	115,510
Canada	—	—	5,033	18,670	579	6,578	95,675	1,124,577	101,288	1,149,829
Chile	—	—	—	—	855	10,562	8,664	101,777	9,519	112,338
Costa Rica	—	—	704	342	—	—	4	58	707	400
Dominican Republic	—	—	2,688	16,231	3,768	44,902	18	190	6,474	61,323
France	6	57	3,182	894	—	—	25	288	3,213	1,239
Guyana	—	—	111	1,170	8	74	290	3,125	410	4,369
Hong Kong	—	—	225	183	—	—	—	—	225	183
Israel	—	—	271	188	—	—	—	—	271	188
Malaysia	—	—	334	1,017	—	—	—	—	334	1,017
Mexico	858	9,493	254	153	276	3,326	111	1,381	1,499	14,352
Netherlands	2	22	1,939	515	—	—	—	—	1,942	537
Panama	—	—	41	194	—	—	246	2,475	287	2,672
Peru	—	—	107	1,222	110	1,276	8,199	92,058	8,416	94,557
Singapore	—	—	1,713	767	—	—	1	13	1,714	781
Switzerland	2	25	6,809	74,415	—	—	12,685	148,867	19,496	223,308
Trinidad and Tobago	—	—	603	5,052	—	—	23	254	626	5,307
United Kingdom	—	—	34	162	—	—	415	4,905	449	5,067
Uruguay	—	—	—	—	—	—	4,487	51,587	4,487	51,587
Yugoslavia	—	—	—	—	—	—	576	6,827	576	6,827
Other	123	1,277	333	3,209	1	18	331	3,957	791	8,454
Total ⁴	992	10,874	24,668	126,264	5,597	66,735	147,491	1,721,576	178,749	1,925,449

¹Because of the implementation of the Harmonized Tariff System in Jan. 1989, import data may not be comparable with previous years' data.

²Bullion also moves in both directions between U.S. markets and foreign stocks on deposit in the Federal Reserve Bank. Monetary gold excluded.

³Includes gold content of base metal ores, concentrates, and waste destined for refining.

⁴Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 14
WORLD GOLD ANNUAL PRODUCTION CAPACITY, RESERVES, AND
RESERVE BASE, DECEMBER 31, 1991

(Metric tons)

Country	Rated mine capacity ^a	Reserves ¹	Reserve base ²
Australia	245	1,400	2,700
Brazil	95	940	1,080
Canada	180	1,780	1,960
China	140	NA	NA
South Africa, Republic of	630	20,000	22,000
U.S.S.R.	280	6,220	7,780
United States	300	4,770	5,250
Other	450	7,920	8,710
World total³	2,320	43,000	49,500

^aEstimated. NA Not available.

¹Reserves listed for countries other than Australia, Canada, the Republic of South Africa, and the United States may, in some instances, include inferred reserves.

²The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).

³Data may not add to totals shown because of independent rounding.

TABLE 15
GOLD: WORLD MINE PRODUCTION, BY COUNTRY¹

(Kilograms)

Country ²	1987	1988	1989	1990	1991 [*]
Argentina	990	962	1,150	¹ 1,200	¹ 1,478
Australia	110,696	156,950	203,563	² 244,137	² 234,218
Bolivia	2,755	4,889	3,595	⁵ 5,198	³ 3,501
Botswana ⁴	31	21	66	45	40
Brazil ⁵	83,700	100,200	¹ 103,000	⁸ 5,000	80,000
Burkina Faso ⁶	7,000	9,300	7,600	7,800	8,000
Burundi	26	14	¹ 18	⁹	² 25
Cameroon ⁷	8	8	8	8	8
Canada	115,818	134,813	159,494	¹ 167,373	¹ 172,708
Central African Republic	223	382	328	² 241	240
Chile	17,035	20,614	22,559	² 27,503	28,000
China ⁸	72,000	78,000	90,000	100,000	120,000
Colombia	² 26,546	² 29,014	² 29,506	² 29,352	30,000
Congo ⁹	16	16	16	16	16
Costa Rica ⁶	300	313	387	⁴ 460	500
Côte d'Ivoire	7	6	13	20	1,100
Dominican Republic	7,651	5,785	5,238	⁴ 4,354	4,000
Ecuador	9,500	8,050	13,000	10,000	12,000
Ethiopia ⁷	643	728	745	⁸ 850	³ 3,038
Fiji	2,962	4,273	4,221	⁴ 4,115	² 2,827
Finland	¹ 1,800	2,035	2,491	² 2,813	2,500
France	2,225	2,753	³ 3,303	⁴ 4,236	3,700
French Guiana	514	530	⁵ 544	⁸ 870	1,000
Gabon ⁸	79	138	81	⁸ 80	80
Germany, Federal Republic of:					
Western states ⁹	26	16	16	18	16
Ghana	10,201	11,601	13,358	16,840	² 26,310
Guinea	(⁹)	¹⁰ 1,300	¹⁰ 2,053	¹⁰ 6,340	4,400
Guyana ⁹	¹ 1,568	2,330	3,200	3,500	5,000
Honduras	131	127	1,244	¹ 1,707	1,700
Hungary ⁹	560	560	500	500	600
India ¹¹	1,864	1,942	1,827	¹ 1,983	¹ 1,973
Indonesia ¹²	3,643	4,738	6,155	11,158	¹ 16,879
Iran ⁹	400	400	400	500	800
Japan	8,590	7,310	6,098	⁷ 7,303	⁸ 8,300
Kenya	278	17	15	25	² 25
Korea, North ⁹	5,000	5,000	5,000	5,000	5,000
Korea, Republic of ¹¹	7,600	11,121	14,270	20,760	21,000
Liberia ¹³	⁴ 467	677	⁷ 734	¹ 600	600
Madagascar	40	90	45	40	40
Malaysia	3,512	2,929	2,884	2,594	² 2,763
Mali ⁹	950	⁴ 2,650	⁴ 3,000	⁴ 5,200	5,500
Mexico	7,988	9,098	8,613	8,338	8,400
Mongolia ⁹	900	1,000	1,200	1,000	800
Mozambique	—	—	—	63	³ 394
Namibia	172	² 240	336	¹ 1,634	¹ 1,857

See footnotes at end of table.

TABLE 15—Continued
GOLD: WORLD MINE PRODUCTION, BY COUNTRY¹

(Kilograms)

Country ²	1987	1988	1989	1990	1991 [*]
New Zealand	¹ 1,216	2,404	⁴ 4,766	⁴ 4,630	⁶ 6,611
Nicaragua	948	878	¹ 1,410	¹ 1,200	¹ 1,154
Papua New Guinea	33,250	38,129	27,538	31,035	⁶ 60,780
Peru	8,486	9,164	⁹ 9,898	⁸ 8,500	9,000
Philippines	32,599	³ 30,482	² 29,992	² 24,591	² 24,938
Portugal	248	267	295	³ 350	360
Romania [*]	⁵ 5,000	⁵ 5,000	⁶ 6,000	⁶ 6,000	5,000
Rwanda [*]	9	15	⁷ 745	700	700
Saudi Arabia	—	¹ 1,000	² 2,900	³ 3,536	3,600
Sierra Leone ¹⁵	467	404	400	400	400
Solomon Islands	¹ 124	47	36	35	30
South Africa, Republic of	⁶ 607,000	⁶ 621,000	607,460	⁶ 605,400	⁶ 601,013
Spain	7,752	8,034	⁸ 8,200	⁸ 8,400	8,000
Sudan	85	300	⁵ 500	¹ 100	50
Suriname [*]	22	30	31	30	30
Sweden	4,108	3,590	5,120	⁶ 6,326	6,300
Taiwan ¹¹	533	236	269	72	—
Tanzania	201	52	116	¹ 1,628	1,500
U.S.S.R.	² 260,000	277,600	³ 304,000	³ 302,000	240,000
United States	153,870	200,914	265,731	² 294,527	² 289,885
Venezuela	3,416	3,502	3,867	7,700	⁴ 4,215
Yugoslavia	⁵ 5,348	4,620	³ 3,741	⁸ 8,190	6,000
Zaire	4,372	3,422	2,032	⁴ 4,236	4,500
Zambia ¹⁶	356	227	¹ 129	¹ 129	120
Zimbabwe	14,710	14,191	16,000	16,900	16,000
Total	¹ 1,660,535	¹ 1,848,448	² 2,023,050	² 2,127,398	2,111,522

^{*}Estimated. [†]Revised.

¹Table contains data available through June 22, 1992.

²Gold is also produced in Burma, Cuba, Czechoslovakia, the Eastern states of Germany, Norway, Senegal, Thailand, and several other countries. However, available data are insufficient to make reliable output estimates. Poland annually mines and processes copper ore estimated to contain about 31,000 kilograms of gold. Disposition of the gold byproduct is unknown.

³Reported figure.

⁴Only the combined total of gold and silver production is reported. For this table, based on the reported silver content of "about 2%" in 1987, gold content of the reported production figure is estimated to be 98% for 1987-91.

⁵Officially reported figures are as follows, in kilograms: Major mines: 1987—13,120; 1988—24,012; (estimated); 1989—24,900 (estimated); 1990—29,986 (revised); and 1991—33,584. Small mines (garimpos): 1987—22,660; 1988—55,053 (estimated); 1989—56,000 (estimated); 1990—72,110 (revised); and 1991—55,525.

⁶Gold purchases by Banco Central from placer deposits and mines; actual production estimated to be at least twice this amount.

⁷Year ending June 30 of year stated.

⁸Does not include undocumented production from small artisanal production.

⁹Revised to zero.

¹⁰Figures include reported mine production of 320 kilograms in 1988; 1,059 kilograms in 1989; 1,600 kilograms in 1990; and 1,450 kilograms in 1991 from the SAG mine. Remainder represents approximate reported sales to Government of artisanal production. Figures do not include artisanal production smuggled out of the country.

¹¹Refinery output.

¹²Excludes production from so-called people's mines, estimated at 15,000 kilograms per year during 1987-91, but includes gold recovered as byproduct of copper mining.

¹³These figures are based on gold taxed for export and include gold entering Liberia undocumented from Guinea and Sierra Leone.

¹⁴Includes production from Kalana Mine and artisanal production. 1990 includes Syama mine production.

¹⁵Data are based on official exports and do not reflect gold moved through undocumented channels.

¹⁶Year beginning Apr. 1 of year listed.

FIGURE 1
HEAP-LEACH PROCESS COMPONENTS

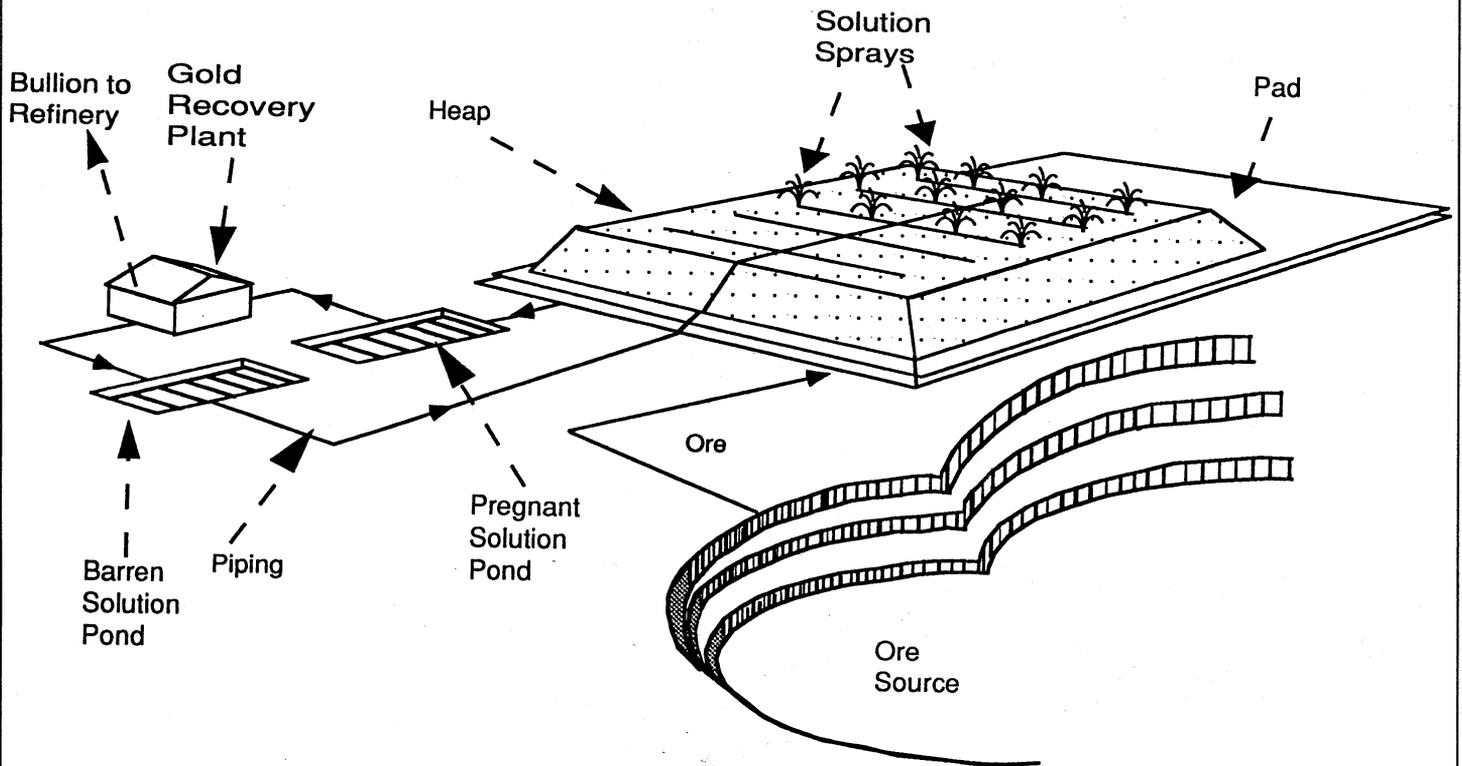
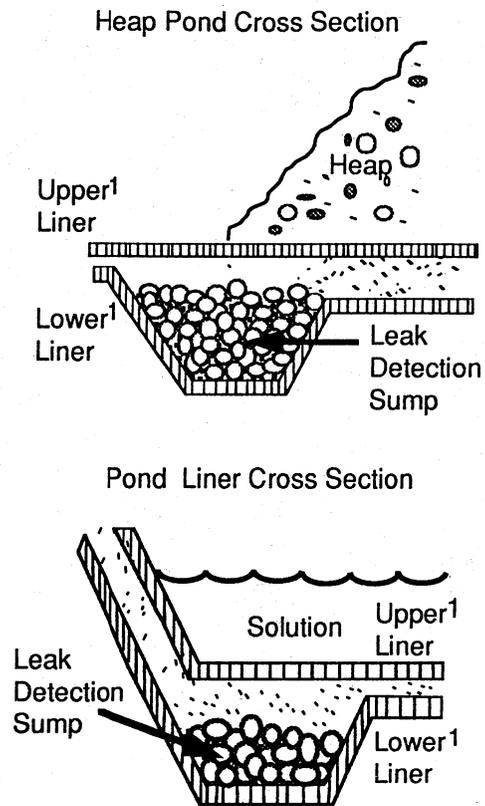
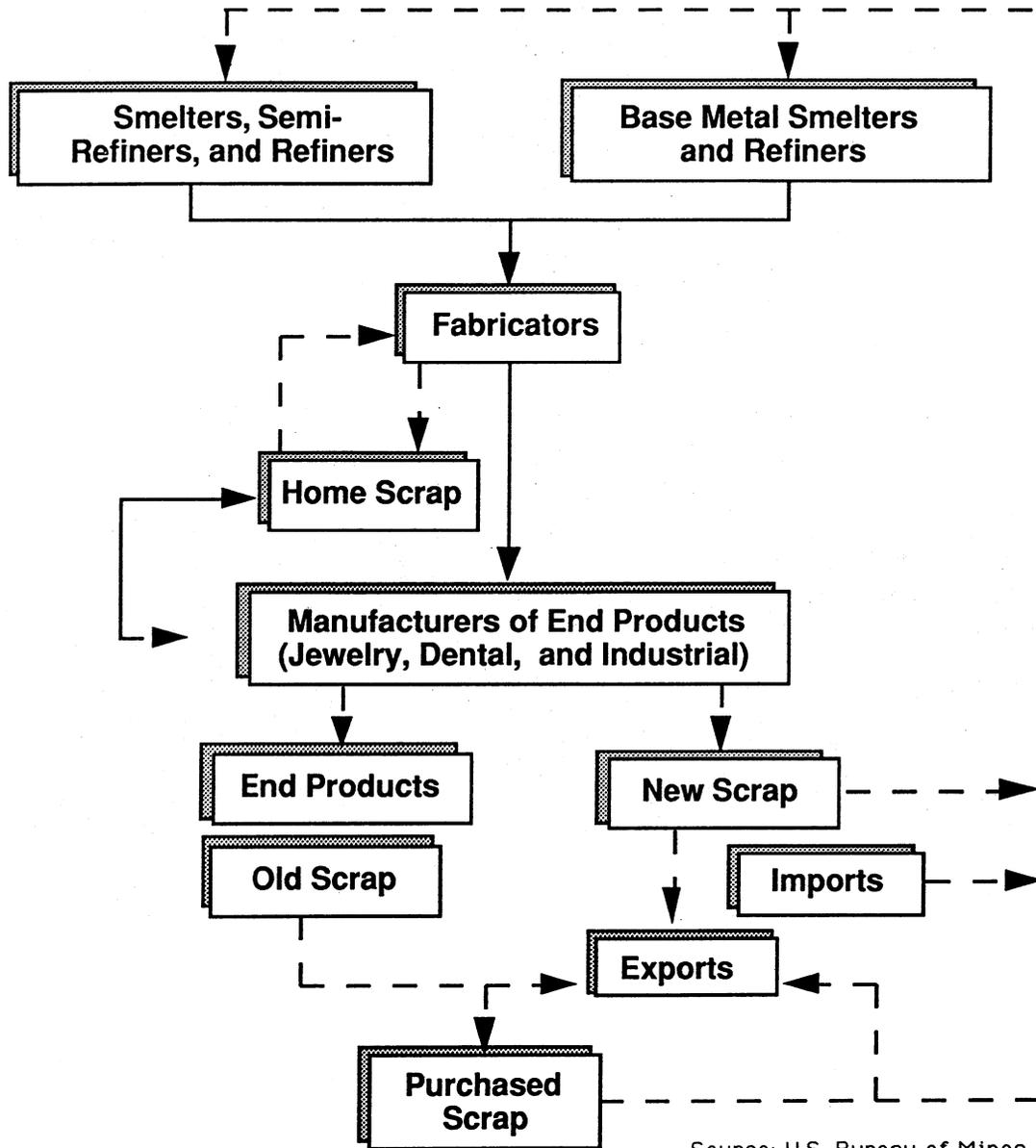


FIGURE 2
HEAP AND POND LINER CROSS SECTIONS



¹ Liners, High density, Polyethylene or polyvinyl chloride 1 mm to 2.5 mm thick (60-100 mils).

FIGURE 3
SECONDARY GOLD CHART



Source: U.S. Bureau of Mines

GRAPHITE

By Harold A. Taylor, Jr.

Mr. Taylor, a physical scientist with 25 years of industry, Federal Government, and U.S. Bureau of Mines experience, has been the commodity specialist for graphite since 1980. Domestic survey data were prepared by William Field, statistical assistant; and international data tables were prepared by Audrey Wilkes, international data coordinator.

Amorphous graphite was not mined domestically in 1991. Graphite supplies exceeded industrial demand to a major degree. Most prices of the major imported graphite increased from those of 1990, and one decreased. Prices did not reflect the severe oversupply. Production of manufactured graphite and graphite fibers decreased 10% and 14%, respectively. (See table 1.)

DOMESTIC DATA COVERAGE

Domestic production data for synthetic graphite are developed by the U.S. Bureau of Mines from a voluntary survey of domestic producers. Of the 32 operations polled, 100% responded. This represented 100% of the total production data shown in table 5.

BACKGROUND

Definitions, Grades, and Specifications

Graphite, a soft crystalline form of carbon, has been called plumbago and black lead. It crystallizes in a lamellar hexagonal system, has a gray to black metallic luster, and is greasy to the feel. It is anisotropic in its physical properties and has a weak plane of cleavage parallel to the lamellae.

The term "amorphous" when applied to graphite is a misnomer. The term "microcrystalline" is more descriptive. The definition of amorphous, as applied to graphite, has been further complicated by longstanding industrial application of the term to very fine particles of crystalline flake graphite that can be sold

only for low-value use such as foundry facings. Fine-grained varieties of lump graphite that are easily reduced to fine particle size by grinding are called amorphous lump to distinguish them from the tough, platy and acicular varieties, known as crystalline lump, that can be reduced in particle size only with extreme difficulty.

Crystalline flake graphite is well defined in paragraph 214 of the Tariff Act of 1930 as follows:

"The term crystalline flake means graphite, or plumbago, which occurs disseminated as a relatively thin flake throughout its containing rock, decomposed or not, and which may or has been separated therefrom by ordinary crushing, pulverizing, screening, or mechanical concentration process, such flake being made up of a number of parallel laminae, which may be separated by mechanical means."

Under the foregoing definition, finely divided particles of crystalline flake graphite would be classified as crystalline graphite. The Court of Customs Appeals, however, has held that commercial designations and not scientific terms must govern classification, and when a commercial meaning differs from the technical meaning, the commercial designation must govern. Therefore, quantities of fine crystalline flake graphite are imported under the amorphous classification.

Sri Lankan lump graphite is classified as amorphous or crystalline. Each type is divided into a number of grades, depending on the size (such as lump, ranging from the size of walnuts to that

of peas; chip, from that of peas to about that of wheat grains; and dust, finer than 60 mesh), graphitic carbon content, and degree of consolidation.

Amorphous graphite is graded primarily on graphitic carbon content. Commercial ore contains about 75% to 93% carbon, depending on the source.

Crystalline flake graphite from Madagascar is divided into two main grades, "flake" (coarse flake) and "fines" (fine flake). Madagascan crucible flake must have a minimum of 85% graphitic carbon and be essentially all minus 20 plus 80 mesh in particle size. Other crystalline flake graphites are also graded according to graphitic carbon content and particle size.

Natural graphite is marketed in the form of crystalline graphite as flake, lump, chip, and dust and in the form of amorphous graphite in sizes from fine powder to lumps up to the size of walnuts. It is common practice to blend different graphite to obtain a product having certain desired physical and chemical properties. In many instances, the composition of these blends is retained as a trade secret.

Geology-Resources

The three principal types of natural graphite—lump, amorphous, and crystalline flake—are based on physical characteristics that are the result of major differences in geologic origin and occurrence. A variety of silicate minerals are generally associated with graphite in the ore.

Lump graphite occurs as fissure-filled veins. It is typically massive, ranging in particle size from extremely fine grains (amorphous) to coarse, platy intergrowths of fibrous to acicular aggregates (crystalline). The origin of vein-type graphite deposits is believed to be hydrothermal.

Amorphous graphite is formed by metamorphism of coalbeds by nearby intrusives. Its purity depends on the purity of the original coalbeds. Amorphous graphite usually is associated with sandstones, shales, slates, and limestones.

Flake graphite commonly occurs disseminated in regionally metamorphosed sedimentary rocks, such as gneisses, schists, and marbles. It is believed that the graphite was formed under the same conditions that caused the metamorphism of the rocks—from carbon deposited with the sediments.

Although the flake graphite deposits of certain countries conform to this description, most of the commercial deposits that are exploited are the result of weathering of these metamorphic rocks, with the graphite being found in lateritic clays that have accumulated at the surface. Graphite, quartz, and other resistant minerals have been freed by weathering of the feldspars, thus lessening the amount of crushing necessary before beneficiation.

World graphite reserves totaled 21.0 million metric tons.¹ Detailed breakouts are given in the 1988 Minerals Yearbook chapter.

Technology

Mining.—In Sri Lanka, lump graphite is mined underground from narrow, steeply dipping veins. The ore is mined principally by overhand stoping and filling, using temporary stulls when necessary to support the walls. Hand drilling is used in most stoping to achieve selective mining and to avoid unwanted fines and product contamination. Drills are used in developing headings. The ore is hauled by truck to the sorting and classification yard.

Amorphous graphite beds are usually mined underground. However, the beds are much thicker than those of amorphous lump and crystalline lump. The ore is drilled, blasted, hand-loaded into cars, and hauled to the surface by conventional methods.

Flake graphite deposits have been mined by underground and surface methods. Underground deposits are usually unweathered and require drilling and blasting. Most surface mining is confined to the weathered part of the deposit, and normal excavating equipment such as power shovels, bulldozers, and rippers is used with a minimum of drilling and blasting. The ore is usually trucked to the mill.

Milling.—Sri Lankan amorphous and crystalline lump graphite are refined by hand cobbing and hand sorting and wiping lumps on wet burlap to remove fines. Light hand sorting and cleaning operations are done by women, while the heavier duties are performed by men.

Most amorphous graphite that requires beneficiation is not worth mining. Preparation for most uses requires grinding only, and coarse impurities are removed by screening or air separation methods.

Flake graphite from disseminated deposits must be concentrated to meet market requirements. Virtually every known concentrating device and combination of separating principles have been tried. The mineral has gained a reputation of being difficult to concentrate, and probably in no other industry has such a large proportion of the mills failed to make commercial recoveries. Graphite actually is one of the easiest minerals to segregate into a rough concentrate, but one of the most difficult to refine.

Because of the premium placed on the mesh size of flake graphite, the problem in milling is one of grinding to free the graphite without reducing the flake size excessively. This is difficult because, during grinding, the graphite flakes are cut by quartz and other angular gangue minerals, thus reducing flake size rapidly. However, if most of the quartz and other

angular minerals are removed, subsequent grinding will usually reduce the size of the remaining gangue, with little further reduction in the size of the flake.

Because graphite floats readily and does not require a collector froth, flotation has become the accepted method for beneficiating disseminated ores. The chief problem lies with depressing the gangue minerals. Relatively pure grains of quartz, mica, and other gangue minerals inadvertently become smeared with the soft, fine graphite, making them floatable and resulting in the necessity for repeated cleaning of the concentrates to attain high-grade products.

Substitutes

Some interchange of the various types and grades of natural graphite and between manufactured and natural graphite takes place, but the degree is difficult to determine. Manufactured graphite does not compete with natural graphite in most uses because of its greater cost. Manufactured graphite is not substitutable for natural flake graphite in clay-bonded graphite crucibles, although some crucibles are machined from manufactured graphite for special uses. Calcined coke and other carbons are satisfactory substitutes for graphite for certain foundry core and mold washes and are used when they can compete in terms of price and supply. Other carbons with high purity can be used in batteries.

Economic Factors

The price structure of graphite is quite complex because of the wide variety of products and the lack of standard market quotations. Prices quoted in trade journals are only a range negotiated between buyer and seller and sometimes do not reflect the real market. Quotations are available in Industrial Minerals, Chemical Marketing Reporter, and the U.S. Bureau of Mines Annual Report. However, average declared import values per ton for amorphous and crystalline graphite have been available for years from U.S. Bureau of the Census data.

The cost for domestically produced graphite from new mines would be much higher than that for graphite from the major foreign sources, for the same type and purity. The high cost of production results from high labor costs and the low graphite content of the ore.

Taxes.—Graphite producers are granted a 22% depletion allowance for tax purposes on domestic lump and amorphous and 14% on domestic flake and on foreign operations.

Tariffs.—Duties on graphite items imported from most favored nations (MFN) are minimal. Graphite from the U.S.S.R. and certain other nations is subject to a higher duty. (See table 2.)

Operating Factors

Environmental Requirements.—Natural graphite is an inert nontoxic substance, and environmental requirements are limited to dust control and certain organic vapors arising from ingredients blended with it to manufacture products.

Employment.—Production and marketable natural graphite requires little hand labor, except for the graphite mined in Sri Lanka. Even in areas of low-cost labor, mechanical methods are used to mine and concentrate flake graphite.

Because of the small size of the domestic natural graphite industry, no publishable employment data are available. Because there is only one small mine open intermittently and the product is beneficiated and processed to a minimal extent, employment probably does not exceed 50. Much of the imported graphite requires grinding, perhaps further refining, mixing with other grades to meet consumer specifications, bagging, and shipping. The total number of persons engaged in these operations, including marketing, probably does not exceed 500.

ANNUAL REVIEW

Legislation and Government Programs

No acquisitions of graphite from the strategic and critical materials stockpile occurred in 1991. Sales of Madagascar crystalline flake from the stockpile totaled 106 tons in 1991 compared with 453 tons in 1990. (See table 3.)

Production

United Minerals Co. continued its suspension of production of its amorphous graphitic material from its Montana mine in 1991. Output of manufactured graphite decreased 10% to about 229,000 tons, at 29 plants, with a likelihood of some unreported production for in-house use. Production of all kinds of graphite fiber and cloth decreased 14% to 3,243 tons.

The graphite fiber industry had some important changes in 1991, mostly caused by oversupply of high-modulus fiber in weak markets. Courtaulds Ltd. sold its Grafil operation in California at midyear and closed its plant at Coventry, United Kingdom. The firm cited a severe overbuilding of capacity that destroyed profitability. Mitsubishi Rayon Co. bought the Grafil operation, and Courtaulds will continue to supply its precursor. In the fall, Amoco Performance Products Inc. announced a downsizing of its composites operation and a 2-month suspension of high-modulus fiber production to cut inventories. The firm offered a voluntary severance program to shrink employment. It has been heavily dependent on defense-related business.

Hoechst AG and Horsehead Industries Inc. announced a merger of their subsidiaries, Sigri GmbH and Great Lakes Carbon Corp., effective yearend. Sigri will be the majority partner, and the new firm will be headquartered in Germany. (See tables 4, 5, and 6.)

Consumption and Uses

Reported consumption of natural graphite decreased 16% to about 35,610 tons, according to a survey of more than 230 users. The three major uses of natural graphite were refractories, brake linings, and in foundries, which together accounted for 58% of reported consumption. (See table 7.)

Nonclay refractories represent two important uses categories of graphite. Standard refractory products, particularly gunning and ramming mixes, accounted for a sizable part of the demand in the past 5 years, mainly as amorphous graphite. Crucibles, shrouds, nozzles, stopper heads, and retorts, used in hot-metal processing operations such as the continuous casting of steel, use significant amounts of crystalline flake. Coarse flake graphite is preferred for crucibles and refractory associated items, but generally it is mixed with some fine crystalline material of lower value. The newest important refractory use for graphite in steelmaking is in carbon magnesite brick, where large amounts of crystalline flake are now used.

Graphite is used in brake and clutch linings. More graphite is being used as the brake and clutch producers change over from asbestos. The graphite lubricates, transfers the heat of friction away from the part, and leads to a lower rate of wear. Graphite is more commonly used in heavier duty nonautomobile lining. Low-quality crystalline flake and amorphous graphite are suitable for foundry facing use. The graphite is mixed with a small amount of clay, suspended in an adhesive material, and applied as a thin coating to mold surfaces to provide for clean and easy mold release of the metal castings.

Graphite is important as a lubricant; when used as a lubricant, it can be a dry powder or mixed with oil or water. It is used with materials that must withstand extreme conditions, such as very high temperatures. Material for this use must be free of abrasive-type impurities.

Graphite used in packings, which includes expanded graphite and graphite foil, has been broken out this year for the

first time. While this new category includes uses in ammunition and seed coatings, in addition to packings, most of the tonnage was used to make expanded graphite and graphite foil and final products resulting from them.

Prices

Natural graphite prices are often negotiated between the buyer and seller and are based on purity and other criteria. Therefore, published price quotations such as those in Industrial Minerals are given as a range of prices. Another source of information for graphite prices is the average customs value per ton of the different imported classes. These mainly represent shipments of unprocessed graphite. A third source for natural graphite prices is the amount paid per ton at the point of consumption.

The price for crystalline graphite at the point of consumption—mostly crystalline flake, some crystalline dust, and a little lump graphite—dropped slightly to \$1,579 per ton from \$1,600 (revised). The price for amorphous graphite (including small amounts of amorphous-synthetic graphite mixtures) rose by 22% to \$819 per ton from \$671 per ton (revised). (See tables 8 and 9.)

Foreign Trade

The United States changed its tariff classification to the Harmonized Code on January 1, 1989. This has made the 1988 and 1990-91 import and export statistics somewhat noncomparable.

Total exports of natural graphite increased 68%. Exports of graphite electrodes totaled 105,204 tons valued at \$170.7 million, of which 54,309 tons (\$54.0 million) went to Canada, 6,940 tons (\$15.3 million) to Venezuela, 6,610 tons (\$23.5 million) to Japan, 6,113 tons (\$10.7 million) to Brazil, and the balance to other destinations.

Imports of natural graphite decreased 33% from those of 1990. Imports of natural graphite from all major sources except Mexico dropped drastically. (See tables 10, 11, and 12.)

World Review

This year was a disaster for graphite producers and traders. Customers were living off the graphite stockpiles they were frightened into building by the supposed onset of shortage last year. The economic downturn cutting sales of the customer's products and the prospect of sales from the GSA stockpile exacerbated the situation. The market in other major graphite-consuming nations was in a similar condition for the same reasons. Mercifully, no major new producers came on-stream during 1991; only one Canadian producer of any size operated this year. The Norwegian operation was closed for most of the year. In addition, imports of Chinese graphite into the United States were halved from those of the previous year. Interestingly enough, posted prices were seldom lowered, although market participants reported drastic discounts.

Australia.—Gwalia Consolidated Ltd. agreed in principle to proceed with the Munglinup crystalline flake graphite project, then put it on hold at yearend. The completed engineering study indicated that it would cost \$9 million and take 9 months to finish. The operation would have an initial capacity of 3,000 to 4,000 tons per year and an ultimate capacity of 10,000 tons. The Western Australian Mines Dept. has approved the project.

Canada.—A paper describing the Lades-Iles flake graphite deposit of Stratmin Inc. was presented at the Society for Mining Metallurgy and Exploration (SME) Annual Meeting. The firm began its geophysical work in 1987 using electromagnetic methods. The deposit is in a Precambrian Grenville sedimentary belt. The formation sequence in the pit begins with a biotite-garnet gneiss, overlain by a band of quartzite, superimposed by a marble body, followed by another quartzite band, itself overlain by a biotite-garnet gneiss. The graphite in the deposit itself is concentrated in the marble core with lesser amounts found in the quartzite.

The mill has a complex flowsheet with 11 flotation stages; nevertheless, the product obtained was better than expected, running 96% C and even sometimes more than 97.5% C. The firm is anticipating a production of 17,500 tons in 1992.²

Stratmin announced in November that it would resume operating its concentrator on a full-time basis. It had been operated only on a part-time basis since April because of large inventories and unexpectedly good performance of the concentrator.

Korea, North.—Kyowa Shoji Co. of Japan formed a joint venture, called Jisong Graphite Joint Venture, to produce 50,000 tons of graphite per year from the Fungsan Mine. This will represent more than a doubling of national production.

Mexico.—Minera Montemayor SA de CV has bought an amorphous graphite mine 100 km northeast of San Ignacio. The mine is presently producing at the 8,000-ton-per-year level. The new owners plan to increase this to about 18,000 tons per year by mid-1992. This would be a major increase in Mexican graphite production, if implemented. The mine's main markets have been domestic.

Namibia.—Rossing Uranium Ltd. engaged Van Eck & Lurie (Pty.) Ltd. to build a modular graphite processing pilot plant at Rossing's graphite deposit. The plant is part of Rossing's evaluation of its crystalline flake graphite deposit at Otjiwarongo, 300 km north of Windhoek. The plant has crushing, screening, milling, flotation, and filtration modules, plus a drying, screening, and bagging plant for completing the products. The 2 tons of ore per hour capacity plant will make a variety of products with different purities and flake sizes, as adjusted to customer's needs. The ore grade ranges from 3.6% to 12% graphite. Rossing had previously investigated a large low-grade deposit near Usakos.

Graphite also occurs in the south in the Namaqualand granites. The Aukam Mine produced from this source.

Norway.—Elkem A/S bought the Skaland crystalline flake graphite operation from Graphitwerk Kropfmuhl late in the year. The operation was closed for most of the year. Elkem is modifying and upgrading the operation.

South Africa, Republic of.—MINTEK and the South African Development Trust Corp. Ltd. have begun exploration of the Steamboat crystalline flake graphite deposit. It is 50 km southwest of Alldays in the far northern part of Transvaal Province. Reserves delineated to a depth of 100 m totaled 2.5 million tons with a content of 8.8% flake graphite. Additional reserves may extend for 3 km to the east. Beneficiation tests gave more than a 90% recovery of a product containing more than 90% carbon.

Current Research

A new U.S. Bureau of Mines-developed process for the recovery of crystalline flake graphite from kish moved a step closer to implementation. Kish is a graphitic waste produced in steelmaking when the excess carbon in the hot metal crystallizes out and associates with the slag or is collected in the bag house. In March 1991, the U.S. Bureau of Mines signed a Memorandum of Agreement with The Asbury Graphite Mills Inc. and Inland Steel Co. to assess the quality, quantity, and cost of using the new process. Inland Steel will construct and operate a bench-scale system and a 1-ton-per-day-capacity pilot plant at its Indiana Harbor steel plant. Asbury Graphite will evaluate and test the pilot plant product through the refractorymakers it serves. The U.S. Bureau of Mines will assist in the design and operation of the bench-scale system and the plant.

A number of new end uses for fullerenes were developed this year, some of them involving graphite. This was the result of a major breakthrough late in 1990, when a simple preparation method was discovered for fullerenes. It involves heating graphite rods in a vacuum chamber and collecting the fullerene-rich

soot deposited on the chamber surfaces. The fullerenes are related to graphite even though they are not graphite compounds but are a separate class of carbon materials. Fullerenes have complex configurations of approximately 60 or more carbon atoms, the best known of which are shaped like a soccer ball. A class of microtubular fullerenes arranged in spiraling scrolls of sheets of carbon atoms has been discovered. These are not true fullerenes since the carbon atoms are arranged in a hexagonal geometry like that of graphite. There will probably be additional classes of fullerenes discovered, such as the just-discovered helical and thin-film ones.

Buckminsterfullerene can be swiftly crushed to diamond at room temperature, much more simply than the current methods of producing synthetic diamonds. Rapid nonhydrostatic compression of this fullerene to about 20 gigapascals efficiently transforms this material instantaneously into bulk polycrystalline diamond at room temperature in a diamond anvil cell. The process probably works so efficiently because the fullerene crystal structure is sterically fairly close to the one of diamond; graphite's structure has much less resemblance. It is also possible to grow diamond crystals on top of ultrathin fullerene films.

Researchers suggested a number of other uses for fullerenes. MicroMet Technology Inc. of Charlotte, NC, has discovered a new type of steel made with fullerenes that it calls Rhondite. Its carbon molecules are linked in chains wrapped around iron atoms, and this cablelike structure in turn wraps around a larger core of iron. Rhondite is said to be 1.5 times as strong as conventional steel and 300% more durable than major high-performance metals. It can be made on existing steelmaking equipment at a realistic cost. Fullerenes might be usable to lubricate gears in micromotors, although they do oxidize and break down when heated. A strong, light material might be made from fused fullerenes, and fullerenes appear to superconduct and to change the wavelength of light. Because fullerenes can give up and immobilize

electrons, they should be good catalysts. (See table 13.)

OUTLOOK

Projected demand for crystalline flake graphite totaled 23,000 tons for 1995 and 25,000 tons for the year 2000. Demand for other graphite, mostly amorphous, totaled 15,000 tons for 1995 and 13,000 tons for the year 2000. This very slow growth rate reflects the maturity of the market, mostly in refractories, and particularly in carbon-magnesite brick.

¹All tonnages are reported in metric tons, unless otherwise noted.

²Goffaux, D. Stratmin Graphite, Inc. A Unique Graphite Mine Story. Presented at Soc. Min. Met. and Expl., Littleton, CO, Feb. 24-27, 1992. AIME preprint 92-104, 15 pp.

OTHER SOURCES OF INFORMATION

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Industrial Minerals (London).
Materials Engineering.
Wall Street Journal.

TABLE 1
SALIENT NATURAL GRAPHITE STATISTICS

		1987	1988	1989	1990	1991
United States:						
Production	metric tons	—	W	W	—	—
Apparent consumption	do.	31,634	42,799	50,867	38,676	14,170
Exports	do.	11,700	11,068	11,452	11,537	19,374
Value	thousands	\$6,218	\$5,815	\$7,421	\$9,481	\$11,345
Imports for consumption	metric tons	43,334	53,867	62,319	50,213	33,544
Value	thousands	\$17,654	\$23,238	\$33,707	\$35,222	\$21,662
World: Production	metric tons	'643,156	'650,168	'652,322	'644,379	628,894

*Estimated. *Revised. W Withheld to avoid disclosing company proprietary data.

TABLE 2
U.S. IMPORT DUTIES

Tariff item	HTS No.	Most favored nation (MFN) Jan. 1, 1992	Non-MFN Jan. 1, 1992
Crystalline flake, (not including flake dust):	2504.10.10	0.7 cents per kilogram ¹	3.6 cents per kilogram.
Other powder	2504.10.50	Free	10% ad valorem.
Other	2504.90.00	do.	Do.

¹Duty temporarily suspended.

TABLE 3
U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND STOCKS OF NATURAL GRAPHITE IN 1991, BY TYPE

(Metric tons)

Type	Goal	National stockpile inventory
Madagascar crystalline flake	12,880	15,550
Sri Lanka amorphous lump	5,715	4,934
Crystalline, other than Madagascar and Sri Lanka	1,750	1,754
Nonstockpile-grade, all types	—	846

Source: General Services Administration, Inventory of Stockpile Materials as of Dec. 31, 1991.

TABLE 4
PRINCIPAL PRODUCERS OF SYNTHETIC GRAPHITE IN 1991

Company	Plant location	Product ¹
Amoco Performance Products Co.	Greenville, SC	Cloth, high-modulus fibers.
Ashland Petroleum Co., Carbon Fibers Div.	Ashland, KY	High-modulus fibers.
BASF Structural Materials Inc.	Rock Hill, SC	Do.
Carbone of America	St. Mary's, PA	Motor brushes and unmachined shapes.
Courtaulds Grafil Co.	Sacramento, CA	High-modulus fibers.
Fiber Materials, Inc.	Biddeford, ME	Other.
Fiber Technology Corp.	Provo, UT	Do.
Fortafil Fibers Inc.	Rockwood, TN	High-modulus fibers.
BF Goodrich Co., Engineered Systems Div., Super Temp Operation.	Santa Fe Springs, CA	Other.
Great Lakes Carbon Corp.	Hickman, KY	
Do.	Morganton, NC	Electrodes, unmachined shapes, motor brushes, other.
Do.	Niagara Falls, NY	Do.
Do.	Ozark, AR	Do.
Hercules Inc.	Salt Lake City, UT	High-modulus fibers.
HITCO Materials Group, British Petroleum Co. Ltd.	Gardena, CA	Cloth.
National Electrical Carbon Co.	Fostoria, OH	Motor brushes, unmachined shapes, cloth.
NAC Carbon Prod., Inc.	Punxsutawney, PA	Other.
Pfizer Minerals, Pigments & Metals Div.	Easton, PA	Do.
Polycarbon, Inc.	Valencia, CA	Cloth.
Showa Denko Carbon Inc.	Ridgeville, SC	Electrodes.
Stackpole Fibers Co., Div. of Zoltek Corp.	Lowell, MA	High-modulus fibers.
Superior Graphite Co.	Russellville, AR	Electrodes.
Do.	Hopkinsville, KY	Other.
Textron Corp., Avco Specialty Materials Div.	Lowell, MA	High-modulus fibers.
The Carbon/Graphite Group Inc.	Niagara Falls, NY	Anodes, electrodes, crucibles, unmachined shapes, motor brushes, refractories, other.
Do.	St. Mary's, PA	Do.
The Carborundum Co., Metallics Systems Div.	Sanborn, NY	Crucibles, unmachined shapes.
UCAR Carbon Company, Inc.	Clarksburg, WV	Anodes, electrodes, unmachined shapes, crucibles, other.
Do.	Clarksville, TN	Do.
Do.	Columbia, TN	Do.

¹Cloth includes low-modulus fibers; motor brushes include machined shapes, crucibles include vessels.

TABLE 5
U.S. PRODUCTION OF SYNTHETIC GRAPHITE, BY END USE

End use	1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Anodes	5,511	17,618	4,442	\$13,003
Cloth and fibers (low-modulus)	380	29,232	234	14,650
Crucibles and vessels and refractories	(¹)	(¹)	(¹)	(¹)
Electric motor brushes and machined shapes	3,139	21,902	1,269	15,222
Electrodes	169,798	363,319	154,397	327,360
Graphite articles ²	—	39,379	—	32,210
High-modulus fibers	3,394	181,138	3,009	127,129
Unmachined graphite shapes	4,413	33,622	5,891	39,704
Other	3,130	78,044	2,408	62,422
Total	189,765	764,254	171,650	631,700
Synthetic graphite powder and scrap ³	64,611	34,297	57,473	32,525
Grand total	254,376	798,551	229,123	664,225

¹Revised.

²Crucibles and vessels and refractories end products included in "Other" products category.

³Includes all items for which no quantity data are available.

⁴Includes steelmaking carbonraisers, additives for metallurgy, and other powder data.

⁵Data do not add to totals shown because of independent rounding.

TABLE 6
U.S. PRODUCTION OF GRAPHITE FIBERS

Year	Cloth and low-modulus fibers		High-modulus fibers		Total	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1981	196	\$15,293	371	\$21,759	567	\$37,052
1982	192	17,706	549	30,091	741	47,797
1983	171	14,217	670	33,854	841	48,071
1984	202	17,979	1,052	56,436	1,254	74,415
1985	287	27,235	1,439	84,743	1,726	111,978
1986	149	17,895	1,373	76,622	1,522	94,517
1987	231	23,706	1,583	84,559	1,814	108,265
1988	239	28,228	2,176	117,754	2,415	145,982
1989	377	34,846	2,538	128,603	2,915	163,449
1990	380	29,232	3,394	181,138	3,774	210,370
1991	234	14,650	3,009	127,129	3,243	141,779

TABLE 7
U.S. CONSUMPTION OF NATURAL GRAPHITE, BY USE

Use	Crystalline		Amorphous ¹		Total ²	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989:	19,245	\$30,295	20,325	\$15,861	39,570	\$46,156
1990:						
Batteries	W	W	W	W	319	505
Brake linings	2,021	2,955	4,889	4,723	6,910	7,678
Carbon products ³	288	742	114	142	402	884
Crucibles, retorts, stoppers, sleeves, nozzle	W	W	W	W	1,391	1,716
Foundries ⁴	825	878	3,475	1,164	4,300	2,042
Lubricant group:						
Lubricants	1,577	2,147	4,185	1,219	5,762	3,366
Packing; other ⁵	3,035	5,873	303	476	3,338	6,349
Pencils	892	1,183	237	128	1,129	1,311
Powdered metals	1,386	2,901	37	66	1,423	2,967
Refractories	4,024	5,823	7,793	5,625	11,817	11,448
Rubber	W	W	W	W	1,205	469
Steelmaking	W	W	W	W	1,174	657
Other ⁶	1,342	2,724	1,705	2,210	3,047	4,934
Withheld uses	1,839	2,333	2,251	1,014	—	—
Total	17,229	27,559	24,989	16,767	42,217	44,326
1991:						
Batteries	214	384	—	—	214	384
Brake linings	2,060	2,958	3,976	3,321	6,036	6,279
Carbon products ³	464	1,480	296	291	760	1,771
Crucibles, retorts, stoppers, sleeves, nozzles	W	W	W	W	1,136	1,521
Foundries ⁴	827	1,123	2,798	1,510	3,625	2,633
Lubricant group:						
Lubricants	514	991	848	778	1,362	1,769
Packing; other ⁵	2,888	5,408	166	338	3,054	5,746
Pencils	1,598	2,295	254	169	1,852	2,464
Powdered metals	1,513	2,642	45	87	1,558	2,729
Refractories	4,051	4,630	6,980	5,723	11,031	10,353
Rubber	45	104	1,229	819	1,274	923
Steelmaking	W	W	W	W	1,167	792
Other ⁶	628	1,601	1,912	2,398	2,540	3,999
Withheld uses	1,253	1,739	1,050	574	—	—
Total	16,055	25,355	19,552	16,008	35,607	41,363

²Revised. W Withheld to avoid disclosing company proprietary data; included with "Withheld uses." 1990 included in "total" for 1991.

¹Includes mixtures of natural and manufactured graphite.

²Data may not add to totals shown because of independent rounding.

³Includes bearings and carbon brushes.

⁴Includes foundry facings.

⁵Includes ammunition, packings, and seed coating.

⁶Includes paints and polishes, antilock and other compounds, soldering and/or welding, electrical and electronic products, mechanical products, magnetic tape, small packages, industrial diamonds and drilling mud and other use categories.

TABLE 8
REPRESENTATIVE YEAREND GRAPHITE PRICES

(Per metric ton)

	1990	1991
Industrial minerals:		
Crystalline large flake, 85% to 90% carbon	\$820- \$1,300	\$650- \$1,200
Crystalline medium flake, 85% to 90% carbon	770- 1,120	450- 1,000
Crystalline small flake, 80% to 90% carbon	540- 900	400- 600
Powder (200 mesh), 95% to 97% carbon	770- 1,000	770- 1,000
Powder (200 mesh), 97% to 99% carbon	1,000- 1,300	1,000- 1,300
Amorphous powder, 80% to 85% carbon	220- 440	220- 440
Custom value, at foreign ports:		
Flake	935	970
Lump and chip, Sri Lankan	1,216	1,442
Amorphous, Mexican	116	119

Source: Industrial Minerals, No. 279, Dec. 1990, p. 78, and No. 291, Dec. 1991, p. 78.

TABLE 9
INDEXES OF UNIT VALUE OF GRAPHITE FIBER
PRODUCED IN THE UNITED STATES¹

(1973 = 100)

Year	Cloth and low-modulus fibers	High-modulus fibers
1980	125	50
1981	129	46
1982	146	48
1983	129	45
1984	146	43
1985	149	50
1986	176	51
1987	153	50
1988	179	57
1989	164	52
1990	166	50
1991	160	38

¹The indexes were calculated from company data most representative of the industry and are not based solely on data shown in table 5.

TABLE 10
U.S. EXPORTS OF NATURAL AND ARTIFICIAL GRAPHITE, BY COUNTRY

Country	Natural ¹		Artificial ³		Total	
	Quantity (metric tons)	Value ²	Quantity (metric tons)	Value ²	Quantity (metric tons)	Value ²
1990:						
Brazil	332	\$800,456	1,188	\$2,442,945	1,520	\$3,243,401
Canada	3,769	2,394,059	16,690	7,262,105	20,460	9,656,164
France	217	103,349	1,243	3,197,257	1,460	3,300,606
Germany, Federal Republic of	542	560,828	1,070	669,536	1,612	1,230,364
Italy	86	259,254	271	242,728	357	501,982
Japan	556	744,063	1,588	4,977,240	2,144	5,721,303
Korea, Republic of	66	46,331	316	927,057	381	973,388
Mexico	2,566	1,542,476	1,528	793,269	4,094	2,335,745
Netherlands	508	395,088	2,417	1,330,545	2,925	1,725,633
United Kingdom	365	349,342	2,563	1,538,004	2,928	1,887,346
Venezuela	915	750,788	398	537,539	1,312	1,288,327
Other	1,614	1,535,299	3,813	7,706,698	5,428	9,241,997
Total⁴	11,537	9,481,333	33,085	31,624,923	44,622	41,106,256
1991:						
Brazil	80	216,216	181	435,096	261	651,312
Canada	3,208	2,135,735	17,404	7,539,970	20,612	9,675,705
France	652	276,538	1,037	1,139,599	1,689	1,416,137
Germany, Federal Republic of	206	325,814	704	685,519	910	1,011,333
Italy	66	84,201	307	1,150,908	372	1,235,109
Japan	397	721,375	3,554	4,674,655	3,951	5,396,030
Korea, Republic of	129	77,227	1,542	2,644,693	1,671	2,721,920
Mexico	8,244	3,338,789	1,648	864,996	9,892	4,203,785
Netherlands	204	71,562	5,638	2,550,154	5,842	2,621,716
United Kingdom	240	159,315	1,370	740,372	1,611	899,687
Venezuela	2,548	1,667,876	484	547,418	3,032	2,215,294
Other	3,400	2,270,492	3,793	6,902,448	7,193	9,172,940
Total	19,374	11,345,140	37,662	29,875,828	57,036	41,220,968

¹Amorphous, crystalline flake, lump or chip, and natural, not elsewhere classified. Harmonized Tariff Schedule (HTS) Nos. 2504.10.0000 and 2504.90.0000.

²Customs value.

³Includes artificial graphite and colloidal or semicolloidal graphite. HTS Nos. 3801.10.0000 and 3801.20.0000.

⁴Data may not add to totals shown because of independent rounding.

Source: Department of Commerce, Bureau of the Census.

TABLE 11
U.S. IMPORTS FOR CONSUMPTION OF NATURAL GRAPHITE, BY COUNTRY

Country	Crystalline flake		Lump or chippy dust		Other natural crude and refined		Amorphous		Total	
	Quantity (metric tons)	Value ¹ (thou- sands)	Quantity (metric tons)	Value ¹ (thou- sands)	Quantity (metric tons)	Value ¹ (thou- sands)	Quantity (metric tons)	Value ¹ (thou- sands)	Quantity (metric tons)	Value ¹ (thou- sands)
1989	11,922	\$10,881	675	\$693	24,064	\$18,776	25,658	\$3,357	62,319	\$33,707
1990:										
Austria	40	20	—	—	—	—	—	—	40	20
Belgium- Luxembourg	—	—	—	—	2	41	—	—	2	41
Brazil	1,455	1,996	—	—	213	307	—	—	1,668	2,303
Canada	5,162	5,038	—	—	4,449	4,068	—	—	9,611	9,106
China	10,047	6,628	—	—	5,036	3,409	1,615	264	16,698	10,301
France	—	—	—	—	15	147	—	—	15	147
Germany, Federal Republic of	276	721	—	—	7	65	—	—	283	786
Hong Kong	—	—	—	—	—	—	732	69	732	69
India	117	102	—	—	180	213	—	—	297	315
Japan	884	1,120	—	—	20	177	—	—	904	1,297
Madagascar	2,763	2,965	—	—	2,536	2,517	—	—	5,299	5,482
Mexico	40	10	—	—	1,567	997	10,570	1,224	12,177	2,231
South Africa, Republic of	100	59	—	—	—	—	—	—	100	59
Sri Lanka	—	—	565	687	—	—	—	—	565	687
Switzerland	—	—	—	—	289	50	—	—	289	50
United Kingdom	102	43	—	—	—	—	—	—	102	43
Zimbabwe	1,281	1,111	—	—	—	—	—	—	1,281	1,111
Other	141	1,143	—	—	9	31	—	—	150	1,174
Total	22,408	20,956	565	687	14,323	12,022	12,917	1,557	50,213	35,222
1991:										
Austria	—	—	—	—	—	—	20	10	20	10
Brazil	1,379	2,293	—	—	250	405	—	—	1,629	2,698
Canada	2,878	2,264	—	—	2,774	2,175	—	—	5,652	4,439
China	4,621	2,922	—	—	2,812	1,908	269	40	7,702	4,870
France	48	40	—	—	25	240	—	—	73	280
Germany, Federal Republic of	123	254	—	—	41	59	—	—	164	313
Hong Kong	—	—	—	—	—	—	187	29	187	29
India	184	327	—	—	140	165	—	—	324	492
Japan	302	1,204	—	—	53	723	—	—	355	1,927
Madagascar	1,655	1,608	—	—	1,732	1,108	—	—	3,387	2,716
Mexico	79	29	—	—	1,322	849	11,104	1,322	12,505	2,200
Netherlands	—	—	—	—	(²)	2	—	—	(²)	2
Norway	38	16	—	—	—	—	—	—	38	16
South Africa, Republic of	139	198	—	—	—	—	—	—	139	198
Sri Lanka	—	—	434	626	—	—	—	—	434	626
Switzerland	5	16	—	—	—	—	—	—	5	16
United Kingdom	60	94	—	—	—	—	—	—	60	94
Zimbabwe	790	671	—	—	80	65	—	—	870	736
Total	12,301	11,936	434	626	9,229	7,699	11,580	1,401	33,544	21,662

¹Customs values.

²Less than 1/2 unit.

Source: Department of Commerce, Bureau of the Census.

TABLE 12
U.S. IMPORTS FOR CONSUMPTION OF GRAPHITE ELECTRODES,
BY COUNTRY¹

Country	Graphite electrodes ²	
	Quantity (metric tons)	Value ³ (thousands)
1990:		
Belgium	1,096	\$2,226
Canada	1,975	2,422
China	217	328
France	331	863
Germany, Federal Republic of	5,558	9,177
Italy	8,316	15,016
Japan	6,817	13,966
Mexico	12,298	16,132
Spain	626	1,228
United Kingdom	537	992
Other	548	1,147
Total⁴	38,317	63,499
1991:		
Belgium	225	465
Canada	1,689	1,820
China	231	360
France	187	472
Germany, Federal Republic of	1,582	2,926
India	571	979
Italy	5,842	10,846
Japan	5,035	11,335
Mexico	9,516	13,259
Spain	990	1,760
United Kingdom	385	271
Other	618	1,142
Total	26,871	45,635

¹The artificial graphite imports category was reported through 1989. However, the category has been excluded from this table due to substantial delays in obtaining complete data for accurate comparison and reporting in the current period.

²Electric furnace electrodes; HTS No. 8545.11.0000.

³Customs values.

⁴Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 13
WORLD GRAPHITE PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ²	1987	1988	1989 ^p	1990	1991 ^o
Argentina	216	24	100	^o 100	100
Austria	39,391	7,577	15,307	^o 22,205	10,000
Brazil (marketable) ³	31,404	34,520	^o 31,700	^o 30,000	32,000
Burma ⁴	—	—	—	^o 45	40
China ^o	185,000	200,000	200,000	200,000	200,000
Czechoslovakia ^o	^o 20,000	^o 15,000	^o 14,676	^o 12,171	12,000
Germany, Federal Republic of	9,891	9,666	^o 10,600	^o 10,437	10,500
India (mine) ⁵	42,589	57,325	^o 58,000	^o 61,000	60,000
Korea, North ^o	25,000	25,000	35,000	35,000	35,000
Korea, Republic of:					
Amorphous	106,507	107,767	100,282	^o 98,987	100,000
Crystalline flake	838	678	1,186	^o 703	700
Madagascar	13,169	14,106	15,863	^o 18,036	18,000
Mexico:					
Amorphous	36,674	47,871	38,304	^o 23,916	^o 30,148
Crystalline flake	1,787	1,735	1,942	^o 997	^o 1,256
Norway	—	—	1,800	^o 6,930	650
Romania ^o	12,000	12,000	^o 10,000	^o 10,000	10,000
Sri Lanka	9,400	8,547	4,163	^o 5,469	5,000
Turkey (mine)	11,760	12,911	11,302	^o 12,000	12,000
U.S.S.R. ^o	84,000	84,000	84,000	80,000	75,000
United States	—	W	W	—	—
Zimbabwe	13,530	11,441	18,147	^o 16,383	16,500
Total	^o 643,156	^o 650,168	^o 652,322	^o 644,379	628,894

^oEstimated. ^pPreliminary. ^rRevision. W Withheld to avoid disclosing company proprietary data.

¹Table includes data available through May 9, 1991.

²In addition to the countries listed, Canada produced graphite during the period covered by this table but output is unreported because of company confidentiality.

³Does not include the following quantities sold directly without beneficiation, in metric tons: 1985—16,425; 1986—19,074; 1987—10,505; 1988—18,269 (estimated); and 1989—20,000 (estimated).

⁴Data are for fiscal year beginning Apr. 1 of that stated.

⁵Indian marketable production is 10% to 20% of mine production.

⁶Reported figure.

GYPSUM

By Lawrence L. Davis

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Demand for gypsum products decreased in 1991, a result of decreased construction activity, especially in new housing starts that decreased 15% to 1 million units. Crude gypsum mined, calcined gypsum produced, and shipments of wallboard products were all lower than in 1990.

Sales of gypsum products decreased 15% to 22 million short tons, and value decreased 21% to \$1.3 billion. Increased competition caused lower prices for gypsum products. Imports for consumption of crude gypsum decreased 14% to about 7.6 million tons. Total value of gypsum product exports increased slightly to \$86 million.

DOMESTIC DATA COVERAGE

Domestic production data for gypsum are developed by the U.S. Bureau of Mines from a survey of U.S. gypsum operations. Of the 117 operations to which the annual survey request was sent, 113 responded, representing 97% of the total crude gypsum production shown in tables 1 and 2. Nonrespondents were estimated from monthly and quarterly canvasses or from previous years' data. (See table 1.)

BACKGROUND

Definitions, Grades, and Specifications

Gypsum has a composition of 79% calcium sulfate and 21% water, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, and is used as a commercial and generic term for all calcium sulfate materials. The well-formed transparent crystalline variety is

called selenite. The massive variety is called alabaster and can be easily carved. The fibrous, silky variety is called satin spar. Gypsite is a mixture of clay and gypsum crystals.

Anhydrite is calcium sulfate, CaSO_4 , with no water of crystallization. It is a naturally occurring mineral commonly associated with gypsum. When gypsum is calcined at high temperatures, it is converted to anhydrite.

Commercially calcined gypsum, $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$, is a manufactured hemihydrate product produced by partial calcination of gypsum. It is produced by heating gypsum at temperatures to 350° F. Commonly called plaster of paris, when water is added to form a paste, it quickly sets and hardens to form gypsum again.

Byproduct gypsum is a chemical product of manufacturing processes such as phosphoric acid, hydrofluoric acid, citric acid, and titanium dioxide from ilmenite, consisting essentially of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. The sludge produced from scrubbers in the desulfurization of stack gas in thermal powerplants is also byproduct gypsum.

Keene's cement is anhydrous gypsum plaster with certain accelerator additives. It is produced by special high-temperature calcining. All of these minerals and materials, including the articles molded from the plaster, are commonly called gypsum or plaster.

Industry Structure

The domestic gypsum industry is large and is dominated by a few large vertically integrated companies that mine and calcine gypsum and manufacture plaster

and wallboard products. These companies also sell crude gypsum for use in cement and agriculture. The large wallboard producers, through foreign subsidiaries, produce most of the crude gypsum that is imported to feed coastal wallboard plants. Plants on the east coast import mostly from Canada's Maritime Provinces, while plants on the west coast import gypsum from Mexico. Crude gypsum from Spain, the other major source of U.S. imports, is used mainly by cement plants.

Gypsum production is worldwide, with at least 80 countries known to produce. Because of its wide distribution and plentiful supply, most of the world's production is consumed domestically. Exceptions include Canada and Mexico, which export significant portions of their production to the United States; Thailand and Australia, which export to much of the Southeast Asia market; and Spain, which exports to the United States, Scandinavia, and other countries. In the United States and other industrialized nations, the major use of gypsum is in the manufacture of gypsum wallboard products. Most crude gypsum is mined in rural areas and shipped to urban areas for manufacture into wallboard and ultimate consumption. In developing countries, most gypsum is consumed by local cement plants.

Geology-Resources

Gypsum deposits may be found in any geologic era, but they are most common in the Permian. They are commonly found in association with the source rocks for petroleum. Most massive gypsum

and anhydrite deposits occur as large, lenticular, stratified bodies that were formed by evaporation of seawater in basins that have one or more restricted openings to the sea. The basins range in diameter from a few miles to many hundreds of miles.

Classic evaporite formation involves the deposition of anhydrite, with later hydration of the anhydrite by meteoric waters to gypsum at depths ranging from 0 to 1,000 feet. The depth of hydration is generally related to topography, structure, and climate because these factors affect the depth of ground water and surface water penetration.

Technology

Gypsum deposits are explored to determine their physical and chemical properties and to determine a minable thickness and the ratio of gypsum to anhydrite. The depth of hydration is important in mining because the presence of only a few percent anhydrite is sufficient to render gypsum unusable for making plaster. Adequate samples may be obtained from outcrops or drill cores.

Deposits near the surface are developed by stripping the overburden, developing either single- or multiple-bench open pits, and constructing access and transportation routes. Underground ore bodies are developed by sinking shafts or driving adits, with mining development and production by the room-and-pillar system.

Most domestic gypsum is produced from surface mines using standard open pit mining methods. In a typical domestic mine, the gypsum is drilled and blasted as needed, probably every week or two. Broken gypsum rock, loaded with hydraulic shovel or front-end loader, is hauled to the primary crusher by a fleet of three or four 35-ton haultrucks. All material removed from the mines is crude gypsum. All waste is left in the mine.

The processing of crude gypsum depends on the end use. Gypsum for use in cement is crushed to minus 1½ inch plus ¾ inch. For agricultural or filler use, the gypsum is pulverized to 100 mesh or finer.

To produce plaster and wallboard products, minus-100-mesh gypsum is heated in batch kettles to remove three-quarters of the water of crystallization, converting gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, to the hemihydrate product, $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$. A few rotary kilns are also used, in which case a coarse feed with fines removed is calcined. During the commercial calcining process, gypsum is heated to 250° F for about 2 hours, then the temperature rapidly rises to 300° to 350° F, at which time the calcine, called stucco, is dumped into a hot pit. The calcine is then mixed with various additives, including a retarder or accelerator, and manufactured into prefabricated wallboard products and other plaster and cement products.

Plaster is generally reground calcine, modified with retarders or accelerators and containing various binders such as hair, sisal, fiberglass, aggregates, or colored pigments. Retarders, usually glue, starch, or slaughterhouse byproducts, can increase the setting time to as much as 6 hours. Accelerators, such as metal salts, set plaster, or anhydrite, can reduce the setting time to less than 5 minutes. The plaster is packed in bags and sold under various trade names.

Prefabricated products include lath, veneer base, sheathing, and wallboard. These board products are manufactured by continuous methods on automatic machines that can be adjusted to any of the standard products. A slurry of wet plaster with additives and an accelerator is spread between two moving sheets of paper. Moving through the shaping rolls, the edges are molded and sealed. The green board is run out on a traveling belt until the plaster has set. The board is then cut with a revolving knife into appropriate lengths and slowly passed through a drying kiln.

ANNUAL REVIEW

Production

The United States remained the world's leading producer of gypsum, accounting for 15% of the total world output. Crude gypsum was mined by 32 companies at 61 mines in 20 States. Production decreased 6%. Leading producing States, in descending order, were Oklahoma, Iowa, Michigan, Texas, California, Nevada, and Indiana. These seven States produced more than 1 million tons each and together accounted for 76% of total domestic production.

Leading companies were USG Corp., 11 mines; National Gypsum Co., 7 mines; Georgia-Pacific Corp., 7 mines; Harrison Gypsum Inc., 2 mines; and Briar Gypsum Co., 1 mine. These 5 companies, operating 28 mines, produced 69% of the total crude gypsum.

Leading individual mines, in descending order of production, were USG's Plaster City Mine, Imperial County, CA; USG's Sweetwater Mine, Nolan County, TX; Harrison's Cement Mine, Caddo County, OK; USG's Sperry Mine, Des Moines County, IA; USG's Shoals Mine, Martin County, IN; National's Tawas Mine, Iosco County, MI; USG's Alabaster Mine, Iosco County, MI; USG's Fort Dodge Mine, Webster County, IA; Briar's Briar Mine, Howard County, AR; and National's Sun City Mine, Barber County, KS. These 10 mines accounted for 43% of the national total. Average output for the 61 mines decreased 11% to 253,000 tons.

Gypsum was calcined by 13 companies at 71 plants in 28 States, principally for the manufacture of gypsum wallboard and plaster. Calcined output decreased 13% in tonnage and 14% in value. Leading States, in descending order, were California, Iowa, Florida, Texas, Nevada, and New York. These 6 States, with 28 plants, accounted for 47% of the national output.

Leading companies were USG, 20 plants; National Gypsum, 18 plants; Georgia-Pacific, 10 plants; Domtar, 8 plants; and Celotex, 4 plants. These 5

companies, operating 60 plants, accounted for 84% of the national output.

Leading individual plants were, in descending order of production, USG's Plaster City plant, Imperial County, CA; USG's Jacksonville plant, Duval County, FL; USG's Sweetwater plant, Nolan County, TX; USG's Sperry plant, Des Moines County, IA; USG's Shoals plant, Martin County, IN; Briar's Briar plant, Howard County, AR; USG's Baltimore plant, Baltimore County, MD; National's Tampa plant, Hillsborough County, FL; USG's Stony Point plant, Rockland County, NY; and USG's Fort Dodge plant, Webster County, IA. These 10 plants counted for 30% of the national production. Average calcine production for the 71 U.S. plants was 216,000 tons, a 13% decrease.

A total of 681,000 tons of byproduct gypsum, valued at \$3.1 million, was used, principally in agriculture but some for gypsum wallboard manufacturing. Approximately 78% was of nonphosphogypsum origin compared with 69% in 1990.

According to the Gypsum Association, yearend gypsum wallboard plant capacity for producing 1/2-inch regular wallboard decreased slightly to 24.11 billion square feet per year. Total wallboard shipments were 16.8 billion square feet, 70% of capacity. Continued weakness in the wallboard market caused many plants to operate well below capacity level. Domtar's plant at Florence, CO, remained closed throughout the year, and its plant at Sweetwater, TX, was idle during the second half of the year. Centex American's new plant in Bernalillo, NM, came into production. Its other plant in Albuquerque did not operate. (See tables 2 and 3 and figure 1.)

Consumption and Uses

Apparent consumption, defined as production plus net imports plus industry stock changes, of crude gypsum, including byproduct gypsum, decreased 13% to 23.3 million tons. Net imports provided 33% of the crude gypsum consumed. Apparent consumption of

calcined gypsum decreased to 13% to 15.3 million tons.

Yearend stocks of crude gypsum at mines and calcining plants were 2.4 million tons. Of this, 54% was at calcining plants in coastal States.

Of the total gypsum products sold or used, 5.2 million tons, about 24%, was uncalcined. Uncalcined gypsum, crushed and screened to specifications, is marketed for use in portland cement manufacture, agriculture, and fillers. The cement industry uses gypsum to retard the setting time of concrete.

Finely ground gypsum rock is used in agriculture to neutralize alkaline and saline soils, improve the permeability of argillaceous materials, and provide sulfur and catalytic support for maximum fertilizer utilization and leguminous productivity. Small amounts of very pure gypsum are used as fillers and in glassmaking, papermaking, and pharmaceutical applications. In 1991, 63% of the uncalcined gypsum was used in portland cement, and the remainder was used mainly for agricultural purposes.

Of the total calcined gypsum products, most went into prefabricated products. A small percentage was used in industrial and building plasters. Of the prefabricated products, based on surface square feet, 63% was regular wallboard; 26% was fire-resistant type X wallboard; 4% was 5/16-inch mobile home board; and 3% was water- and/or moisture-resistant board. Lath, veneer base, sheathing, predecorated, and other types made up the balance. Of the regular wallboard, 80% was 1/2 inch and 13% was 5/8 inch.

In descending order, the leading sales regions for prefabricated products were the South Atlantic, Pacific, East North-Central, and Middle Atlantic. Together they accounted for 65% of the total. (See tables 4 and 5, and figure 2.)

Markets and Prices

On an average value-per-ton basis, f.o.b. mine or plant, crude gypsum increased slightly to \$6.09, calcined gypsum decreased slightly to \$15.67, and

byproduct gypsum increased slightly to \$4.49. Prefabricated products were valued at \$76.80 per ton, plasters at \$95.36 per ton, and uncalcined products at \$12.87 per ton.

According to the Department of Commerce, the average producer price of regular 1/2-inch wallboard was 8% lower in 1991 than in 1990, and type X board was 6% lower.¹

Lower demand and lower prices, especially for gypsum wallboard products, continued to cause difficult times for much of the industry. Two companies, Celotex and National, remained under chapter 11 bankruptcy protection.

Foreign Trade

Imports for consumption of crude gypsum decreased 14% to 7.6 million tons. Net imports represented 33% of apparent consumption. Crude gypsum from Canada and Mexico was used mainly to feed wallboard plants in coastal cities. Imports from Spain, the other major source of imported gypsum, were used mostly for portland cement manufacture. Gypsum wallboard imports, principally from Canada, decreased 64% to 108 million square feet. The decrease is a reflection of fewer housing starts in the United States. (See tables 6 and 7.)

World Review

Estimated world production of crude gypsum decreased slightly to 104 million tons. Total world production figures are probably low because, in some countries, significant production was consumed captively and not reported. Also, production from small deposits in developing countries was intermittent and often unreported. The United States remained the world's largest producer of crude gypsum with 15% of the world total.

Canada.—Eastern Gypsum Inc. closed its new gypsum wallboard plant in McAdam, New Brunswick. The facility was still for sale at yearend.

The Gypsum Association in the United States, of which all Canadian wallboard producers were members, reported that yearend capacity of 1/2-inch regular wallboard in Canada was 3.32 billion square feet, a slight decrease compared with that of the previous year.

China.—Two new mines were being planned near Xuzhou in northern Jiangsu Province. The planned output of 600,000 tons per year was to be used to make plaster.²

Dominican Republic.—A U.S. firm was reported to have entered into a joint venture with the Government to mine gypsum in Baharona Province. Production was expected to reach 1 million tons per year.³

Hungary.—Navan Resources PLC, from Ireland, was negotiating a joint-venture agreement with Erc-es Asvanybanyak, the Government-owned minerals company. Navan will receive an equity position in exchange for technology and investment. The operation currently supplies 200,000 tons of crude gypsum for use in cement manufacture and 30,000 tons per year of plaster.⁴

Mexico.—Compania Minera Caopas, S.A. opened a gypsum quarry and plant at Santa Rosalia in California Baja Sur. It was reported to be the largest privately owned gypsum facility in Mexico. Design capacity is 2 million tons per year and current production is nearly one-half of that.⁵

OUTLOOK

More than 90% of the gypsum consumed annually in the United States is used in construction, mainly in gypsum wallboard products, building plasters, and in the manufacture of portland cement. The decline in construction activity that has depressed demand for gypsum products over the past several years appears to be slowing. Gypsum product demand decreased in 1991, but a slow

recovery is expected to take place over the next few years.

¹International Trade Administration (Dep. of Commerce). *Construction Review*. V. 37, No. 6, Nov.-Dec. 1991, p. 41.

²Industrial Minerals (London). No. 292, Jan. 1992, p. 57.

³U.S. Embassy, Santo Domingo, Dominican Republic. State Dep. Telegram 00960, Jan. 31, 1992, p. 4.

⁴Industrial Minerals. No. 286, July, 1991, p. 9.

⁵Rukavina, M. Caopas Eyes New Gypsum Markets. *Rock Products*, Sept. 1991, pp. 31-36.

OTHER SOURCES OF INFORMATION

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- Rock Products.

TABLE 1
SALIENT GYPSUM STATISTICS

(Thousand short tons and thousand dollars)

	1987	1988	1989	1990	1991
United States:					
Active mines and plants ¹	109	112	112	106	112
Crude:					
Mined	15,612	16,390	17,624	16,406	15,456
Value	\$106,977	\$109,205	\$128,448	\$99,567	\$94,199
Imports for consumption	9,717	9,679	9,304	8,726	7,633
Byproduct gypsum sales	688	733	725	735	681
Calcined:					
Produced	17,592	17,274	17,893	17,553	15,358
Value	\$321,645	\$313,251	\$285,659	\$278,607	\$240,663
Products sold (value)	\$2,278,822	\$2,090,786	² \$1,926,676	² \$1,712,848	² \$1,348,714
Exports (value)	\$32,061	\$42,789	\$60,311	\$84,452	\$85,613
Imports for consumption (value)	\$163,581	\$158,169	\$111,012	\$110,205	\$88,141
World: Production	¹ 102,654	¹ 108,113	¹ 108,628	¹ 104,584	¹ 103,544

¹Estimated. ²Revised.

¹Each mine, calcining plant, or combination mine and plant is counted as one establishment; includes plants that sold byproduct gypsum.

²Does not include value of plasters sold.

TABLE 2
CRUDE GYPSUM MINED IN THE UNITED STATES, BY STATE

State	1990			1991		
	Active mines	Quantity (thousand short tons)	Value (thousands)	Active mines	Quantity (thousand short tons)	Value (thousands)
Arizona, New Mexico	6	778	\$5,658	6	648	\$4,874
Arkansas, Kansas, Louisiana	5	1,608	11,413	5	1,482	10,909
California, Nevada, Utah	11	3,209	16,955	13	2,903	14,923
Colorado, South Dakota, Washington, Wyoming	7	522	3,751	7	536	3,670
Indiana, New York, Ohio, Virginia	5	2,046	14,715	5	2,040	12,323
Iowa	6	2,192	14,243	6	2,162	12,285
Michigan	5	2,000	11,511	5	1,721	13,052
Oklahoma	7	2,184	11,154	8	2,356	12,925
Texas	6	1,868	10,166	6	1,609	9,240
Total¹	58	16,406	99,567	61	15,456	94,199

¹Data may not add to totals shown because of independent rounding.

**TABLE 3
CALCINED GYPSUM PRODUCED IN THE UNITED STATES, BY STATE**

State	1990			1991		
	Active plants	Quantity (thousand short tons)	Value (thousands)	Active plants	Quantity (thousand short tons)	Value (thousands)
Arizona, Colorado, New Mexico, Utah	5	661	\$5,689	5	658	\$5,112
Arkansas, Louisiana, Oklahoma	7	1,958	23,263	7	1,596	21,442
California	6	2,031	32,225	6	1,620	21,810
Delaware, Maryland, North Carolina, Virginia	6	1,688	33,174	6	1,485	30,621
Florida	3	1,264	25,474	3	1,162	23,652
Georgia	3	694	10,692	3	549	8,495
Illinois, Indiana, Kansas	6	1,467	22,242	6	1,270	18,835
Iowa	5	1,506	20,351	5	1,420	19,240
Massachusetts, New Hampshire, New Jersey	5	984	18,951	5	887	17,083
Michigan	4	637	11,809	4	653	12,395
Nevada	4	1,191	15,360	4	989	13,330
New York	4	1,053	19,787	4	972	18,445
Ohio	3	415	7,716	3	359	6,446
Texas	6	1,311	15,466	6	1,122	13,623
Washington, Wyoming	4	694	16,408	4	616	10,133
Total¹	71	17,553	278,607	71	15,358	240,663

¹Data may not add to totals shown because of independent rounding.

**TABLE 4
GYPSUM PRODUCTS (MADE FROM DOMESTIC, IMPORTED, AND BYPRODUCT GYPSUM)
SOLD OR USED IN THE UNITED STATES, BY USE
(Thousand short tons and thousand dollars)**

Use	1990		1991	
	Quantity	Value	Quantity	Value
Uncalcined:				
Portland cement	4,355	46,660	3,272	34,647
Agriculture and miscellaneous ¹	2,099	39,143	1,890	31,763
Total	6,454	85,803	5,162	66,410
Calcined:				
Plasters	W	W	W	W
Prefabricated products ²	19,237	1,627,045	16,697	1,282,305
Total calcined³	19,237	1,627,045	16,697	1,282,305
Grand total³	25,691	1,712,848	21,859	*1,348,714

W Withheld to avoid disclosing company proprietary data.

¹Includes byproduct gypsum.

²Includes weight of paper, metal, or other materials and some byproduct gypsum.

³Data do not include plasters.

*Data do not add to total shown because of independent rounding.

TABLE 5
PREFABRICATED GYPSUM PRODUCTS SOLD OR USED IN THE UNITED STATES

Product	1990			1991		
	Thousand square feet	Thousand short tons ¹	Value (thousands)	Thousand square feet	Thousand short tons ¹	Value (thousands)
Lath:						
3/8 inch	14,700	11	\$2,563	11,400	9	\$1,995
1/2 inch	300	(²)	46	300	(²)	43
Other	—	—	—	80	(²)	6
Total³	15,000	11	2,608	11,780	9	2,044
Veneer base	440,040	453	34,940	385,755	400	29,002
Sheathing	253,044	245	33,126	184,947	178	22,124
Regular gypsumboard:						
3/8 inch	433,512	348	41,299	621,924	517	53,861
1/2 inch	10,454,624	9,448	750,560	8,861,284	7,928	550,391
5/8 inch	1,319,403	1,354	62,438	1,389,452	1,450	60,625
1 inch	47,780	56	10,439	92,863	104	19,216
Other ⁴	113,079	75	25,624	123,564	105	14,243
Total³	12,368,398	11,280	890,360	11,089,087	10,103	698,336
Type X gypsumboard	5,513,055	5,977	485,342	4,554,542	4,838	372,957
Predecorated wallboard	106,550	103	33,316	94,100	91	28,840
5/16-inch mobile home board	646,631	516	57,938	634,754	489	54,851
Water/moisture-resistant board	543,184	527	69,516	514,100	499	60,477
Other	114,240	125	19,900	95,626	91	13,673
Grand total³	20,000,142	19,237	1,627,045	17,564,691	16,697	1,282,305

¹Includes weight of paper, metal, or other material.

²Less than 1/2 unit.

³Data may not add to totals shown because of independent rounding.

⁴Includes 1/4-, 7/16-, and 3/4-inch gypsumboard.

TABLE 6
IMPORTS FOR CONSUMPTION OF CRUDE GYPSUM, BY COUNTRY
(Thousand short tons and thousand dollars)

Country	1990		1991	
	Quantity	Value	Quantity	Value
Australia	20	172	34	298
Canada ¹	6,349	45,314	5,379	38,631
China	35	421	2	212
Jamaica	24	163	56	399
Mexico	1,698	8,741	1,738	8,809
Morocco	49	269	12	74
Spain	550	5,696	411	3,508
Other	1	232	1	139
Total²	8,726	61,009	7,633	52,070

¹Includes anhydrite.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 7
SUMMATION OF U.S. GYPSUM AND GYPSUM PRODUCTS TRADE DATA
(Thousand short tons and thousand dollars)

Year	Crude ¹		Plasters ²		Boards ³		Other ⁴	Total ⁵
	Quantity	Value	Quantity	Value	Quantity	Value	Value	Value
Exports:								
1987	4	696	123	14,933	NA	11,444	4,988	32,061
1988	5	668	266	18,694	NA	16,531	6,896	42,789
1989	108	2,286	106	15,914	97	25,140	16,972	60,311
1990	129	5,056	94	18,381	69	30,959	30,056	84,452
1991	74	3,720	96	19,872	105	36,943	25,077	85,613
Imports for consumption:								
1987	9,717	59,171	2	384	715	82,220	21,806	163,581
1988	9,679	59,166	2	670	637	70,866	27,467	158,169
1989	9,304	59,107	3	270	355	29,355	22,280	111,012
1990	8,726	61,009	1	236	272	22,786	26,174	110,205
1991	7,633	52,070	11	258	88	7,842	27,971	88,141

NA Not available.

¹Import and export data for 1989-91 are for "Gypsum; anhydrite," Harmonized Tariff Schedule 2520.10. Data for 1987-88 are for "Plaster rock or gypsum: Not ground and not wholly or partly calcined," TSUS 512.21. The two categories might not be comparable.

²Import and export data for 1989-91 are for "Plasters," Harmonized Tariff Schedule 2520.20. Data for 1987-88 are for "Plaster rock or gypsum: Ground, wholly or partly calcined, or both," TSUS 512.24. The two categories might not be comparable.

³Import and export data for 1989-91 are for "Boards, sheets, panels, tiles and similar articles, not ornamented: Faced or reinforced with paper or paperboard only," Harmonized Tariff Schedule 6809.11. Data for 1987-88 are for "Gypsum or plaster building boards and lat" TSUS 245.70. The two categories might not be comparable.

⁴Import and export data for 1989-91 are for "Boards, sheets panels, tiles and similar articles, not ornamented: Other, Harmonized Tariff Schedule 6809.19 and "Other articles," Harmonized Tariff Schedule 6809.90. Data for 1987-88 are for "Cement of gypsum," TSUS 512.31 and 512.35, "Articles n.s.p.f. of Plaster of Paris," TSUS 512.41, and "Alabaster articles, n.s.p.f.," TSUS 513.94. Data for 1989-91 might not be comparable with that of previous years.

⁵Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 8
GYPSUM: WORLD PRODUCTION, BY COUNTRY¹

(Thousand short tons)

Country	1987	1988	1989	1990	1991 ^a
Afghanistan ^a	3.31	3.31	3.31	3.31	3.31
Algeria ^a	303.14	303.14	303.14	² 275.58	² 168.00
Angola ^a	22.05	62.83	62.83	62.83	62.83
Argentina	682.13	573.38	443.57	^a 440.00	495.00
Australia	1,742.03	1,801.19	¹ 1,980.00	¹ 1,980.00	2,204.64
Austria ³	732.44	795.59	689.43	⁴ 697.83	699.97
Bolivia ^a	^c	^c	^c	^c	^c
Brazil (direct sales plus beneficiated)	726.67	⁸ 831.68	^r ⁸ 825.00	^r ⁸ 825.00	825.00
Bulgaria	337.31	442.03	497.15	544.55	495.00
Burma ⁵	25.24	34.96	34.65	34.20	² 34.00
Canada (shipments) ³	¹ 10,024.50	10,484.81	9,034.61	9,041.23	8,820.00
Chile	259.24	348.23	305.65	² 279.71	370.02
China ^a	7,900.00	8,900.00	8,900.00	8,800.00	9,000.00
Colombia	332.90	338.41	609.58	⁵ 550.00	550.00
Cuba ^a	145.00	145.00	145.00	¹ 165.35	165.35
Cyprus	50.38	36.05	^r ³ 35.00	⁴ 40.79	40.00
Czechoslovakia	849.89	853.34	877.45	⁷ 787.06	770.00
Dominican Republic	65.04	168.65	188.50	⁸ 85.98	90.00
Ecuador	32.19	⁵ 55.12	53.32	^r ⁴ 44.00	² ² 26.00
Egypt	1,199.84	¹ 1,200.00	1,443.41	⁵ 531.66	550.00
El Salvador ^a	4.96	4.96	4.96	4.96	4.96
Ethiopia ^{a 6 7}	1.54	2.09	2.31	2.48	2.09
France ³	<u>5,962.45</u>	<u>6,203.86</u>	<u>6,265.59</u>	<u>⁶6,389.05</u>	<u>6,175.00</u>
Germany, Federal Republic of:					
Eastern states ^a	352.74	352.74	341.72	330.00	NA
Western states (marketable) ³	1,881.66	1,921.34	¹ 1,895.99	¹ 1,980.00	NA
Total ^a	<u>2,234.40</u>	<u>2,274.09</u>	<u>2,237.71</u>	<u>2,310.00</u>	<u>2,150.00</u>
Greece ^a	550.00	550.00	500.00	500.00	450.00
Guatemala	⁵ 56.76	37.97	⁶ 63.13	⁷ 72.27	65.00
Honduras ^a	25.00	25.00	² 27.56	² 27.56	27.56
Hungary ³	¹ 115.08	129.90	¹ 124.56	^r ¹ 123.00	123.46
India	1,911.11	1,570.45	1,696.77	¹ 1,826.54	² 1,712.00
Iran ^{3 8}	⁸ 8,942.02	⁸ 8,430.54	⁸ 8,662.03	⁸ 8,514.32	8,820.00
Iraq ^{3 9}	390.00	390.00	500.00	⁴ 420.00	210.00
Ireland	313.06	359.36	346.13	⁴ 434.31	360.00
Israel ^a	38.58	34.00	34.17	41.89	42.77
Italy ^a	² 1,339	1,430.00	1,380.00	1,380.00	1,325.00
Jamaica	194.34	160.39	85.99	90.62	90.00
Japan ^a	6,600.00	6,900.00	6,900.00	7,000.00	7,000.00
Jordan	126.28	93.55	145.95	¹ 102.19	100.00
Kenya ³	42.79	41.85	40.21	39.68	39.68
Laos ^a	77.16	88.19	114.64	125.00	110.23
Lebanon ^a	2.20	2.20	2.20	2.20	2.20
Libya ^a	200.00	200.00	200.00	200.00	200.00
Luxembourg ^a	^c	^c	^c	^c	^c
Mauritania	20.99	⁶ 6.61	⁷ 7.05	⁸ 8.82	³ 3.00
Mexico	5,043.57	5,268.90	5,941.94	⁵ 5,989.79	6,100.00

See footnotes at end of table.

TABLE 8—CONTINUED
GYPSUM: WORLD PRODUCTION, BY COUNTRY¹

(Thousand short tons)

Country	1987	1988	1989	1990	1991*
Mongolia*	35.27	35.27	35.27	35.27	30.00
Morocco*	500.00	500.00	500.00	500.00	500.00
Nicaragua	8.05	⁷ 7.72	12.75	¹ 14.82	² 18.00
Niger*	—	3.31	3.31	3.31	3.31
Pakistan	494.96	412.55	514.75	⁵ 526.55	530.00
Paraguay	3.42	3.97	4.96	⁴ 4.96	4.96
Peru*	² 252.00	165.35	176.37	165.35	165.35
Philippines*	138.05	141.10	132.28	132.28	130.00
Poland ³	1,242.31	¹ 1,209.25	¹ 1,248.93	⁸ 832.25	830.00
Portugal	356.09	372.62	³ 330.00	³ 330.00	330.00
Romania*	1,650.00	1,760.00	¹ 1,545.00	⁸ 880.00	660.00
Saudi Arabia*	411.17	413.37	413.37	413.37	413.37
Sierra Leone*	4.41	4.41	4.41	4.41	4.41
South Africa, Republic of	384.80	410.25	448.36	⁴ 430.75	² 463.00
Spain	7,368.63	⁸ 8,233.23	⁶ 6,060.00	⁵ 5,500.00	5,500.00
Sudan ³	⁷ 7.72	5.51	11.02	¹ 6.00	3.31
Switzerland*	250.00	250.00	250.00	250.00	250.00
Syria	273.38	197.32	¹ 198.42	¹ 193.40	192.91
Taiwan	1.52	2.69	4.30	¹ 1.92	2.20
Tanzania ³	27.17	21.57	6.50	¹ 7.00	6.61
Thailand	3,341.04	5,014.47	6,037.67	6,342.03	² 7,933
Tunisia*	110.23	110.23	110.23	110.23	110.23
Turkey	332.62	254.88	246.35	250.00	250.00
U.S.S.R.	5,270.19	5,403.57	5,401.37	⁴ 4,960.44	4,400.00
United Kingdom* ³	3,860.00	4,080.00	4,400.00	4,400.00	3,860.00
United States ¹⁰	15,612.16	16,390.13	17,624.08	16,405.83	² 15,456
Uruguay*	110.23	¹ 160.00	110.23	¹ 159.84	159.84
Venezuela	272.27	243.61	365.97	221.57	² 236.00
Vietnam*	30.00	30.00	30.00	30.00	35.00
Yemen	⁵ 55.12	⁶ 66.14	⁶ 69.45	⁷ 72.75	72.75
Yugoslavia	609.99	612.04	⁶ 601.36	⁵ 589.35	495.00
Zambia* ⁹	16.53	16.53	16.53	16.53	16.53
Total	¹ 102,654.49	¹ 108,113.02	¹ 108,627.75	¹ 104,583.63	103,543.93

*Estimated. ¹Revised.

¹Table includes data available through June 29, 1992.

²Reported figure.

³Includes anhydrite.

⁴Less than 1/2 unit.

⁵Data are for years beginning Apr. 1 of that stated.

⁶Data are for years ending July 7 of that stated. Reported in cubic meters and estimated at 2.2 short tons per cubic yard.

⁷Probably does not include production for cement manufacture (normally 3% to 5% of finished cement, equivalent of an additional 12,000 to 15,000 metric tons per year).

⁸Data are for years beginning Mar. 21 of that stated.

⁹For cement production only. Information is insufficient to formulate reliable estimates for output for other uses (plaster, mortar, etc.).

¹⁰Excludes byproduct gypsum.

FIGURE 1
SUPPLY OF CRUDE GYPSUM IN THE UNITED STATES

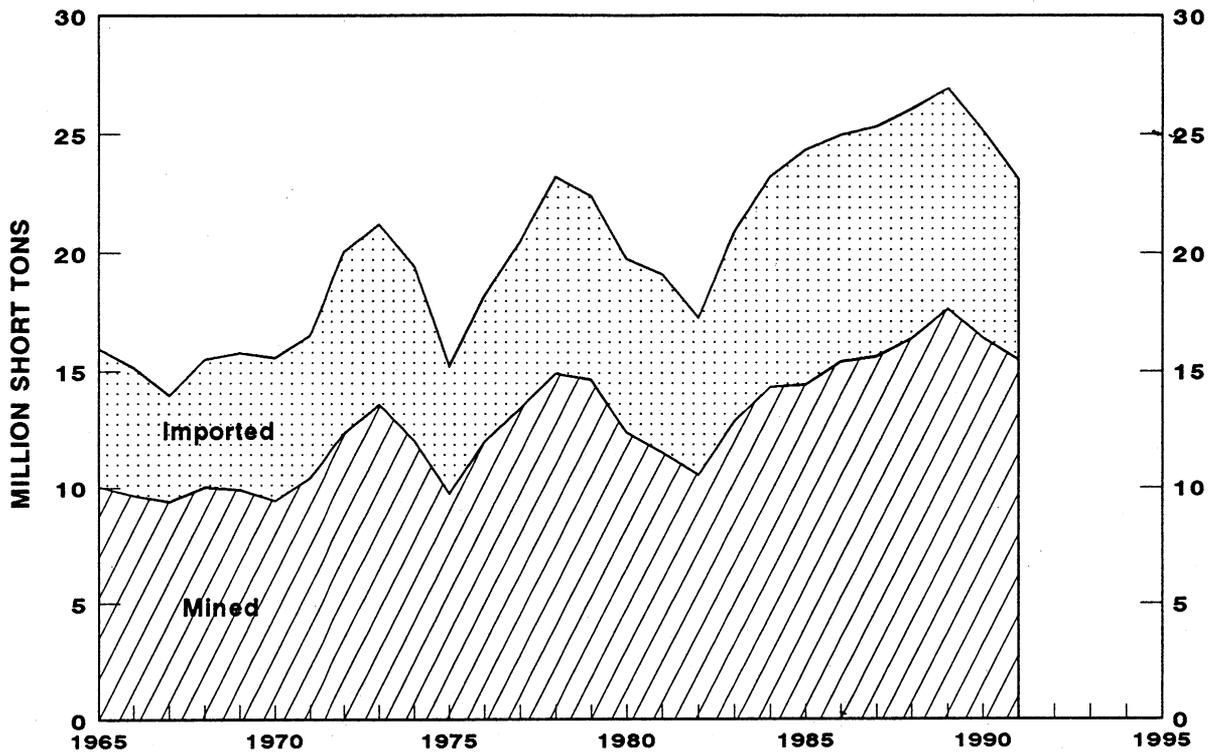
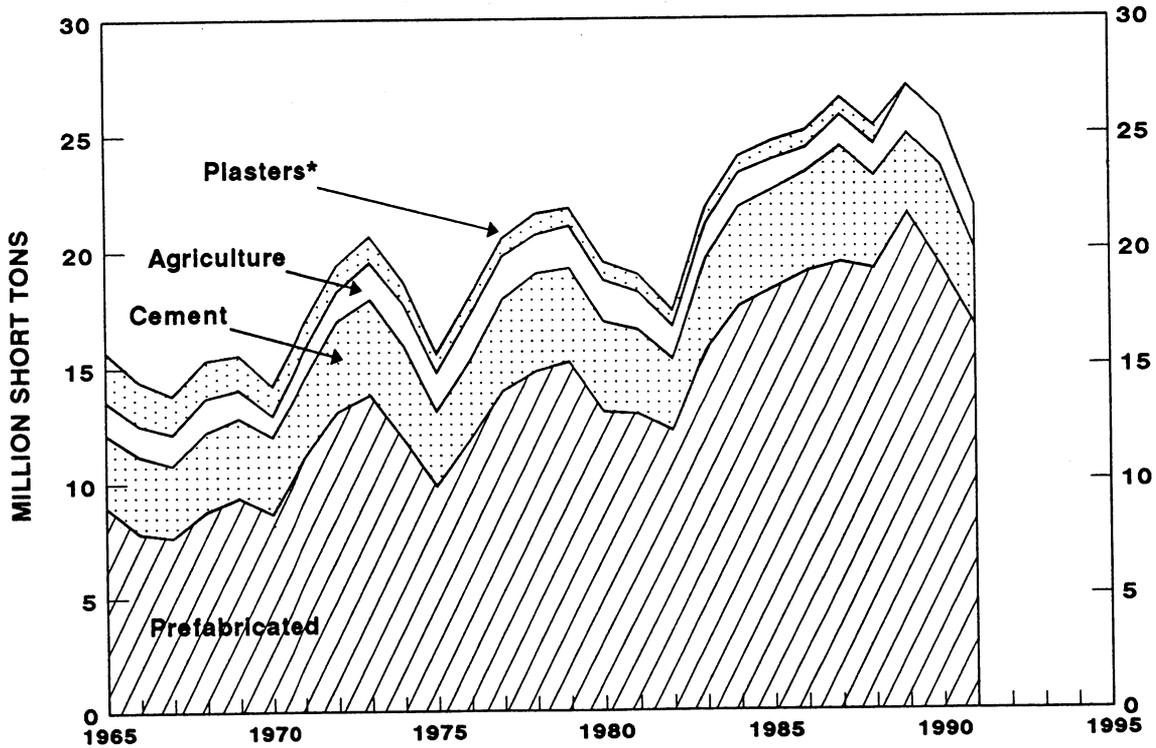


FIGURE 2
SALES OF GYPSUM PRODUCTS BY USE



*Data withheld in 1989 through 1991

HELIUM

By William D. Leachman

Mr. Leachman, a chemical engineer with 38 years of U.S. Bureau of Mines experience, has been the commodity specialist for helium since 1983. He also prepared the domestic survey and international data tables.

Grade-A helium (99.995% or better) sales volume in the United States by private industry and the U.S. Bureau of Mines was 61 million cubic meters [2,198 million cubic feet (MMcf)] in 1991.¹ Grade-A helium exports by private producers were 27 million cubic meters (978 MMcf), for total sales of 88 million cubic meters (3,176 MMcf) of U.S. helium. The Bureau's price for Grade-A helium, f.o.b. plant, was \$1.352 per cubic meter [\$37.50 per thousand cubic feet (Mcf)] and bulk liquid helium was \$1.622 per cubic meter (\$45 per Mcf) on January 1, 1991, with additional costs for container services and rent. On March 1, 1991, the price of gaseous helium was increased to \$1.747 per cubic meter (\$48.45 per Mcf), and the bulk liquid helium price was raised to \$2.017 per cubic meter (\$55.95 per Mcf). The last price increase was made on October 1, 1991, when the price of Grade-A helium was raised to \$1.983 per cubic meter (\$55 per Mcf) and liquid helium prices were raised to \$2.253 per cubic meter (\$62.50 per Mcf). Private industry also increased their helium prices last year, but less than the Bureau's.

DOMESTIC DATA COVERAGE

Domestic production data for helium are developed by the U.S. Bureau of Mines from records of its own operations as well as the High Purity Helium Survey, a single, voluntary canvass of private U.S. operations. Of the eight operations to which a survey request was sent, 100% responded, and those data plus data from the Bureau's operations

represent 100% of the total helium sales and recovery shown in table 2.

BACKGROUND

The U.S. Bureau of Mines role in helium matters dates back to the First World War when the Army and Navy became interested in using helium as an inert lifting gas and contacted the Bureau for assistance because of its natural gas expertise. In 1925, the Government's Helium Program was officially placed under Bureau control by Congress (Helium Act of 1925). In 1929, the Bureau's Amarillo, TX, large-scale helium extraction and purification facility was built and began operation. During World War II, demand increased significantly, and four more small Government helium plants were built.

New technology increased helium demand in the 1950's and led to the construction of the Keyes, OK, plant in 1959. Dwindling Hugoton-Panhandle Field natural gas supplies aroused concerns that no economic source of helium would exist by the turn of the century.

In 1960, Congress replaced the 1925 act with new legislation (Helium Act Amendments of 1960). The purposes of the act were to provide for conservation of helium for essential Government activities and to supply the current and foreseeable future helium needs of the Federal agencies. The act directed the Secretary of the Interior to purchase and store helium for future Government use and to operate and maintain helium production and purification plants and

related helium storage, transmission, and shipping facilities.

Purchases for helium conservation were made under 22-year contracts with private natural gas companies, which added crude helium extraction capabilities to their existing gas processing facilities. Four companies built five crude helium plants. The Bureau constructed a high-pressure pipeline to transport the helium from Bushton, KS, and intermediate points to the Bureau-owned Cliffside Field for storage.

Helium needs of the Federal agencies, particularly the U.S. Department of Defense (DOD), the National Aeronautics and Space Administration (NASA), and the U.S. Department of Energy (DOE), have been met, and there is enough helium in storage to meet their foreseeable needs for up to 100 years, depending on future Government program needs. The entire present Federal helium demand is supplied solely by the Exell Helium Plant.

In the mid-1970's, the Bureau began accepting privately owned crude helium for storage in Cliffside under long-term contracts. Private industry currently has a 7-month supply of helium in Government storage, assuming all private market requirements would be supplied from storage.

Geology-Resources

Domestic measured and indicated helium resources as of January 1, 1991, the latest figures available, are estimated to be 12.8 billion cubic meters [463 billion cubic feet (Bcf)]. The total identified helium resources are about 2.2

billion cubic meters (78 Bcf) less than those reported in 1990. The decrease is attributed to the reevaluation of the undefined indicated helium resources, which are based on the Potential Gas Committee's estimation of potential natural gas resources in the United States. The resources include measured reserves and indicated resources estimated at 6.9 billion cubic meters (249 Bcf) and 0.9 billion cubic meters (32 Bcf), respectively, in natural gas with a minimum helium content of 0.3%. A slight decrease in the measured reserves of helium is reported due to ongoing evaluations of the Nation's depleting helium resources. The change of the pressure and temperature bases at which the resources are reported [14.7 pounds per square inch absolute (psia) and 70° F to 101.325 kilopascals absolute and 15° C] also account for a 2% decrease in the volumes reported. The measured reserves included 1 billion cubic meters (34 Bcf) stored by the Bureau in the helium conservation storage system. Measured helium resources in natural gas with a helium content of less than 0.3% are estimated to be 1.1 billion cubic meters (40 Bcf). Indicated helium resources in natural gas with a helium content of less than 0.3% are estimated to be 3.9 billion cubic meters (143 Bcf). Approximately 4.4 billion cubic meters (160 Bcf) or 92% of the domestic helium resources under Federal ownership are in the Riley Ridge area and the Church Buttes Field in Wyoming and in the Cliffside Field in Texas.

Most of the domestic helium resources are in the midcontinent and Rocky Mountain regions of the United States. The measured helium reserves are in approximately 98 gasfields in 11 States. About 89% of these reserves is contained in the Hugoton Field in Kansas, Oklahoma, and Texas; the Keyes Field in Oklahoma; the Panhandle and Cliffside Fields in Texas; and the Riley Ridge area in Wyoming. The U.S. Bureau of Mines analyzed a total of 223 natural gas samples from 19 States and 1 foreign country during 1991 in conjunction with its program to survey and identify possible new sources of helium.

Technology

Technology that uses liquid helium to produce superconducting temperatures continues to be developed and utilized. Liquid helium continues to be used at Fermi National Accelerator Laboratory for Tevatron/Tevatron 1, which was the world's first superconducting particle accelerator. The liquid helium-cooled superconducting magnets used in this accelerator provide an intense and extremely steady magnetic field using only a fraction of the energy required by conventional electromagnets. The Tevatron is presently the second highest energy particle accelerator in the world (1.6 trillion electron volts). In addition, the DOE has already selected the magnets it proposes to use in the Superconducting Supercollider (SSC). These SSC magnets will be similar to those liquid helium-cooled magnets used at Fermi because they have been proved and tested in operation. When completed, the SSC will have about 20 times the power of the Tevatron (40 trillion electron volts). The Texas site for the SSC was selected by DOE in January 1989.

Argonne National Laboratory is developing a marine magnetohydrodynamic (MHD) propulsion system for military and commercial use. This system has no moving parts, but uses magnetic fields and electricity to pump water through a tube. This method of propulsion was illustrated in the science fiction movie "Hunt for Red October." Researchers at Argonne will use the world's largest helium-cooled superconducting dipole magnet to study the propulsion system. Development of this technology could lead to a new generation of water transportation vessels that would travel more quickly, quietly, and efficiently than present ships.

Liquid helium use in magnetic resonance imaging (MRI) continues to increase as the medical profession accepts and develops new uses for this equipment. MRI equipment is providing accurate diagnosis of medical problems where exploratory surgery was previously required. Another medical application being developed uses MRI to determine

by blood analysis if a patient has any form of cancer. Most researchers seem to think it will be at least 5 to 10 years before the new high-temperature [about -184 °C (-300 °F)] superconducting materials affect liquid helium demand.

Lifting gas applications are increasing. The U.S. Navy and U.S. Air Force are investigating the use of airships to provide early warning systems to detect low-flying cruise missiles. The Drug Enforcement Administration has installed six tethered radar blimps along the southern border of the United States to detect drug smugglers. In addition, NASA is now using helium-filled balloons to sample the atmosphere in Antarctica to determine what is depleting the ozone layer that protects the Earth from harmful ultraviolet radiation. Similar work is also underway in the Arctic. A stealth blimp is being tested by the Army's Intelligence and Electronic Warfare Center in New Jersey. In the commercial market, several companies besides Goodyear are now using "blimps" for advertising.

The development of Strategic Defense Initiative (SDI) weapons such as the antisatellite (ASAT) rocket, chemical laser, and rail gun has slowed with the decline of the "cold war." The ASAT rocket uses liquid helium-cooled infrared sensors for target location and guidance. Gaseous helium is used in the lasing gas mixture of the chemical laser, and liquid helium is used to cool the tracking telescope used to locate the target and aim the laser beam. High-pressure gaseous helium provides the initial push that inserts the projectile into the bore of the rail gun at a velocity of about 1,770 kilometers per hour (1,100 miles per hour). Electromagnetic energy applied along the bore accelerates the projectile to a final velocity of about 14,500 kilometers per hour (9,000 miles per hour). Superconducting magnetic energy storage (SMES) is also being investigated to provide power for DOD laser systems and electric power peak shaving in commercial applications. SMES allows the accumulation and storage of electrical energy over the long term (hours) when excess capacity is available and

discharges it in minutes or as needed to provide for peak demands.

Other evolving technologies that require the unique properties of helium are (1) metastable helium for energy storage, which involves raising helium electrons to an excited energy state and then stabilizing the atom there; (2) fiberoptic production, where an ultrapure atmosphere is required; (3) helium-filled plastic pillows, where low density is required to simulate a precursor wave from a nuclear blast; (4) helium ion tumor treatment, where large inert particles are required; (5) liquid helium-cooled superconducting microswitches, called Josephson junctions, which are much faster than conventional semiconductors and use less power; (6) "aneutronic" nuclear fusion where nuclear energy is produced by fusion of deuterium and helium-3, which produces few or no neutrons; and (7) helium-hydrogen breathing mixtures that enable deep-sea divers to reach depths below 580 meters (1,700 feet).

ANNUAL REVIEW

Legislation and Government Programs

The Administration is proposing legislation to amend the Helium Act of 1960 to remove the requirement that all Federal agencies buy their major helium requirements exclusively from the Secretary of the Interior. This means they could buy helium from private industry helium vendors or the U.S. Bureau of Mines, whichever they choose.

The Federal Helium Program is designed to provide all Federal agencies with their current and foreseeable-future helium needs to carry out other Government programs authorized and funded by Congress. The Bureau's major helium customers are DOD, NASA, and DOE.

Production

In 1991, 14 privately owned domestic helium plants were operated by 10 companies. Eight of the privately owned

plants and the U.S. Bureau of Mines plant extracted helium from natural gas. All extraction plants except one use cryogenic extraction processes. The volume of helium recovered from natural gas increased 34%, while sales increased about 4% in 1991. A shortage of private helium production was prevented by purifying crude helium that had been stored in the Bureau's Cliffside Field. All natural gas processed for helium recovery came from gasfields in Colorado, Kansas, New Mexico, Oklahoma, Texas, and Wyoming. Eight private plants and the Bureau's plant purified helium this year. Pressure-swing adsorption is used for helium purification at seven of the private helium plants and at the Bureau's plant. Cryogenic purification is used by the other producer. The Bureau also uses cryogenic purification for backup. The Bureau and seven private plants that produce Grade-A helium also liquefy helium. The plant operators and locations are Air Products and Chemicals Inc., Hansford County, TX; and Liberal, KS; Navajo Refined Helium Co., Shiprock, NM; Kansas Refined Helium Co., Otis, KS; Exxon Co., U.S.A., Shute Creek, WY; and Union Carbide Corp., Linde Div., Bushton and Ulysses, KS. Nitrotec's helium plant near Burlington, CO, produces Grade-A helium but does not liquefy helium. Linde's helium plant at Elkhart, KS, was shut down in 1988. (See tables 1, 2, and 3, and figures 1 and 2.)

Consumption and Uses

The major domestic end uses of helium were cryogenics, welding, and pressurizing and purging. Minor uses included synthetic breathing mixtures, chromatography, leak detection, lifting gas, heat transfer, and controlled atmospheres. The Pacific and Gulf Coast States were the principal areas of helium consumption.

Bureau sales to Federal agencies and their contractors totaled 9.399 million cubic meters (339 MMcf) in 1991, a decrease of about 16% when compared with last year's sales. This decrease was due largely to the helium price increases

during the year and reduced SDI spending as the cold war declined. Sales to DOE also continue to decline.

The Federal agencies purchase their major helium requirements from the U.S. Bureau of Mines. Direct helium purchases by DOD, NASA, DOE, and the National Weather Service constituted most of the Bureau's Grade-A helium sales. Most remaining helium sales to Federal agencies were made through Bureau contract distributors, who purchased equivalent volumes of Bureau helium under contracts described in the Code of Federal Regulations (30 CFR 602). Some of the contract distributors also have General Services Administration helium supply contracts. These contracts make relatively small volumes of helium readily available to Federal installations at lower freight charges by using the contractors' existing distribution systems. (See figure 3.)

Stocks

The volume of helium stored in the U.S. Bureau of Mines helium conservation storage system, which includes the conservation pipeline network and the Cliffside Field near Amarillo, TX, for future use totaled 1 billion cubic meters (34.3 Bcf) at yearend. The conservation storage system contains crude helium purchased under contract by the Bureau and privately owned helium stored under contract. Excess helium production of private industry extracted from natural gas supplying fuel markets in the winter is stored by the U.S. Bureau of Mines under contract. This privately owned crude helium is returned as needed to the owners for purification to supply private industry demand. During 1991, 26.6 million cubic meters (958 MMcf) of private helium was delivered to the Bureau's helium conservation storage system and 18.7 million cubic meters (675 MMcf) was withdrawn for a net increase of 7.9 million cubic meters (283 MMcf) of private helium in storage. (See table 4.)

Transportation

All Grade-A gaseous helium sold by the Bureau was shipped in cylinders, modules (large gas cylinders), special railway tankcars, or highway tube semitrailers. Small gas cylinders are filled at the Amarillo plant, and railway tankcars are filled at the Exell plant. Other shipping containers for gaseous helium can be filled at either plant. Bureau liquid helium was shipped in dewars and semitrailers from the Exell plant. Private producers and/or distributors shipped helium predominantly as a liquid in semitrailers. These semitrailers delivered the liquid helium to distribution centers where some of it was gasified and compressed into trailers and small cylinders for delivery to the end user. The remaining liquid helium was sold as bulk liquid or repackaged in dewars of various sizes for delivery.

Prices

The U.S. Bureau of Mines price for Grade-A helium, f.o.b. plant, was \$1.352 per cubic meter (\$37.50 per Mcf) and bulk liquid helium was \$1.622 per cubic meter (\$45 per Mcf) on January 1, 1991, with additional costs for container services and rent. On March 1, 1991, the price of gaseous helium was increased to \$1.747 per cubic meter (\$48.45 per Mcf) and the bulk liquid helium price was raised to \$2.017 per cubic meter (\$55.95 per Mcf). The last price increase was made on October 1, 1991, when the price of Grade-A helium was raised to \$1.983 per cubic meter (\$55 per Mcf) and liquid helium prices were raised to \$2.253 per cubic meter (\$62.50 per Mcf). Private industry also increased their helium prices last year, but lagged behind the Bureau's.

Foreign Trade

Exports of Grade-A helium, all by private industry, increased by 10% in 1991 to 27.1 million cubic meters (928 MMcf) (table 3). About 49% of the exported helium was shipped to Europe. Belgium-Luxembourg, France, and the United Kingdom, collectively, received

about 85% of the European helium imports. About 35% of the U.S. helium exports went to Asia, with Japan receiving about 89%. Other exports were as follows: about 8% to North America; about 2% each to Australia-New Zealand, Middle East, and South America; and less than 1% each to Africa, the Caribbean, and Central America. The shipments of large volumes of helium to Western Europe were attributed to helium uses in cryogenic research and superconducting equipment. Significant volumes were also being used in breathing mixtures for diving, welding, and as a lifting gas. Although no helium was imported by the United States in 1991, import tariffs on helium remained at the 3.7% rate established on January 1, 1987. No further decreases in import tariffs are scheduled.

World Review

World production of helium, excluding the United States, was estimated to be 11 billion cubic meters (400 MMcf), most of which was extracted in Poland and the U.S.S.R. The remainder was produced in small plants in China and India. (See table 5.)

OUTLOOK

Until recently, all superconductors required liquid helium [-269° C (-452°F)] to reach superconducting temperatures. Current research on superconductors has resulted in the discovery of superconducting materials that operate above liquid nitrogen temperatures [-196° C (-320° F)]. These new superconductors have physical limitations, such as brittleness and poor current-carrying capacities, which have precluded their use in most superconducting applications. If these physical problems are solved, the new materials could replace liquid helium-cooled superconductors.

Since 1987, the market for U.S.-produced helium has grown at an average annual rate of 9%. Private industry's market has been growing at 10% per year, while the Federal market has grown

at 6%. At the present time, private industry is supplying about 85% of the domestic demand for U.S.-produced helium, while the Bureau is supplying the remaining 15%. Private industry supplies all of the U.S. helium exports. The foreign market made up about 31% of U.S. helium sales in 1991 and has grown at an average rate of almost 19% per year since 1987.

At the present time, the outlook for helium looks good with growth continuing in new technologies that use helium. An adverse impact from high-temperature superconductors, if any, is not expected for several years.

¹All helium volumes herein reported are at 101.325 kilopascals absolute (14.696 psia) and 15° C (59° F). One thousand cubic feet (1 Mcf) at 14.7 psia and 70° F = 27.737 cubic meters at 101.325 kilopascals absolute and 15° C. One cubic meter at 101.325 kilopascals and 15° C = 36.053 ft³ at 14.7 psia and 70° F.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Helium. Ch. in Commodity Annual Report, annual.

Helium. Ch. in Minerals Commodity Summary, annual.

Research 1990-91 Helium Section, annual.

Information Circular 9129, Analyses of Natural Gases, 1917-85, by B. J. Moore and Stella Sigler.

Information Circular 9290, Analyses of Natural Gases, 1990, by John E. Hamak and Stella Sigler.

Information Circular 9301, Analyses of Natural Gases, 1986-1990, by John E. Hamak and Stella Sigler.

Information Circular 9267, Helium Resources of the United States, 1989, by Richard D. Miller and John E. Hamak.

TABLE 1
OWNERSHIP AND LOCATION OF HELIUM EXTRACTION PLANTS
IN THE UNITED STATES IN 1991

Category and owner or operator	Location	Product purity
Government-owned:		
U.S. Bureau of Mines	Masterson, TX	Crude and Grade-A helium. ¹
Private industry:		
Air Products and Chemicals Inc.	Hansford County, TX	Grade-A helium. ¹
Do.	Liberal, KS	Do.
Enron Helium Co.	Bushton, KS	Crude helium.
Exxon Co. U.S.A.	Shute Creek, WY	Grade-A helium. ¹
Kansas Refined Helium Co.	Otis, KS	Do.
KN Energy, Inc.	Scott City, KS	Crude helium. ²
National Helium Corp.	Liberal, KS	Crude helium.
Navajo Refined Helium Co.	Shiprock, NM	Grade-A helium. ¹
Nitrotec	Burlington, CO	Grade-A helium.
Oxy NGL, Inc.	Ulysses, KS	Crude helium.
Phillips Petroleum Co.	Dumas, TX	Do.
Do.	Hansford County, TX	Do.
Union Carbide Corp., Linde Div.	Bushton, KS	Grade-A helium. ¹
Do.	Elkhart, KS	Deactivated.
Do.	Ulysses, KS	Grade-A helium. ¹

¹Including liquefaction.

²Output is piped to Ulysses, KS, for purification.

TABLE 2
HELIUM RECOVERY IN THE UNITED STATES¹

(Thousand cubic meters)

	1987	1988	1989	1990	1991
Crude helium:					
U.S. Bureau of Mines total storage	-8,018	-9,969	-10,471	-12,837	-9,551
Private industry:					
Stored by U.S. Bureau of Mines	20,258	17,495	15,176	14,064	26,580
Withdrawn	^r -19,340	-15,311	-18,120	-21,265	-18,105
Total private industry storage	^r 918	2,184	-2,943	-7,201	8,475
Total crude helium	^r -7100	-7,785	-13,414	-20,038	-1,076
Stored private crude helium withdrawn from storage and purified by the U.S. Bureau of Mines for redelivery to industry	-188	-331	-152	-178	-613
Grade-A helium:					
U.S. Bureau of Mines sold	7,395	8,791	9,712	11,170	9,399
Private industry sold	54,468	62,602	70,153	73,665	78,702
Total sold	61,863	71,394	79,865	84,835	88,101
Total stored	^r -7,288	-8,115	-13,566	-20,216	-1,689
Grand total recovery	^r 54,575	63,278	66,299	64,619	86,412

^rRevised.

TABLE 3
TOTAL SALES OF
GRADE-A HELIUM
PRODUCED IN
THE UNITED STATES

(Million cubic meters)

Year	Domestic sales	Exports ¹	Total sales
1987	48	14	62
1988	53	18	71
1989	58	22	80
1990	60	25	85
1991	61	27	88

¹Source: Bureau of the Census.

TABLE 5
WORLD GRADE-A HELIUM
PRODUCTION CAPACITY,
DECEMBER 31, 1991

(Million cubic meters)

	Capacity
United States	¹ 105
Rest of world*	11
Total*	116

*Estimated.

¹Includes capacity of plants on standby as well as operating plants.

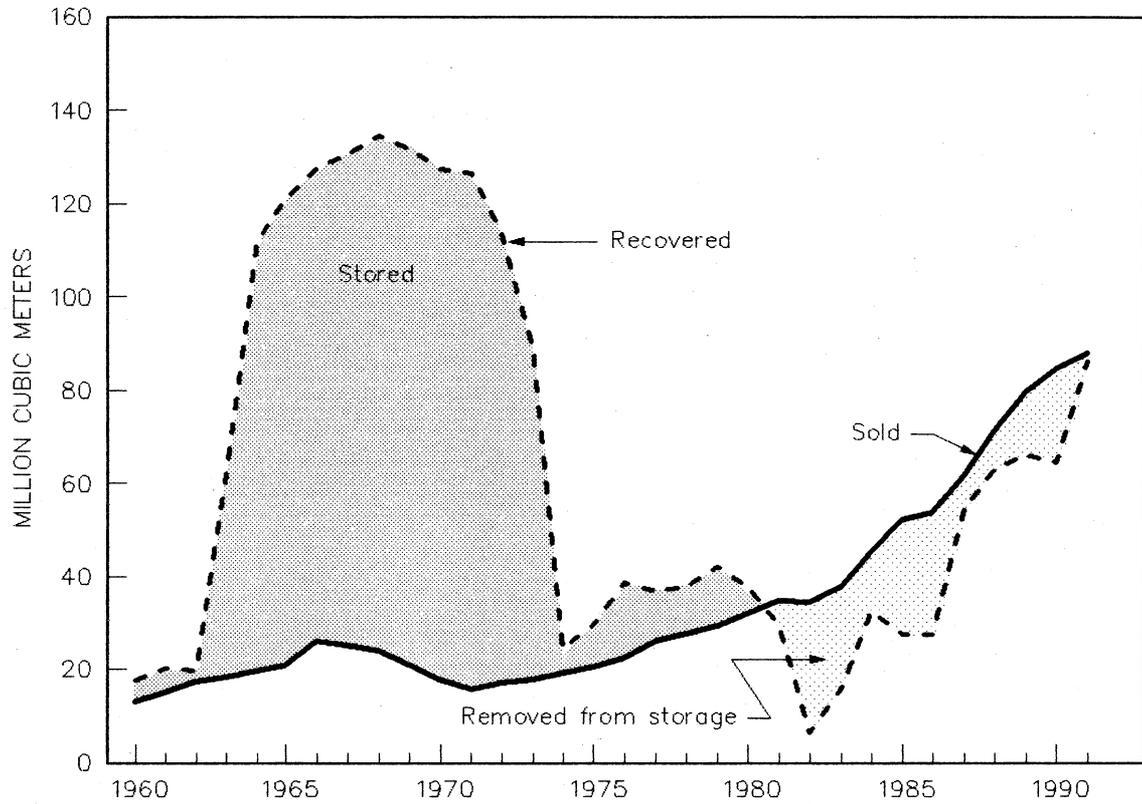
TABLE 4
SUMMARY OF U.S. BUREAU OF MINES HELIUM CONSERVATION
STORAGE SYSTEM OPERATIONS¹

(Thousand cubic meters)

	1989	1990	1991
Helium in conservation storage system at beginning of period:			
Stored under U.S. Bureau of Mines conservation program	936,307	925,836	912,999
Stored for private producers under contract	51,774	48,679	41,300
Total	988,081	974,515	954,299
Input to system:			
Net deliveries from U.S. Bureau of Mines plants ²	-10,471	-12,837	-9,551
Stored for private producers under contract	15,176	14,064	26,580
Total	4,706	1,227	17,029
Redelivery of helium stored for private producers under contract ²	-18,272	-21,443	-18,718
Net addition to system²	-13,566	-20,216	-1,689
Helium in conservation storage system at end of period:			
Stored under U.S. Bureau of Mines conservation program	925,836	912,999	903,448
Stored for private producers under contract	48,679	41,300	49,161
Total	974,515	954,299	952,610

¹Crude helium is injected into or withdrawn from the Bureau's underground storage facility, a partially depleted natural gas reservoir in Cliffside Field near Amarillo, TX.

**FIGURE 1
HELIUM RECOVERY IN THE UNITED STATES**



**FIGURE 2
MAJOR U.S. HELIUM-BEARING NATURAL GAS FIELDS**

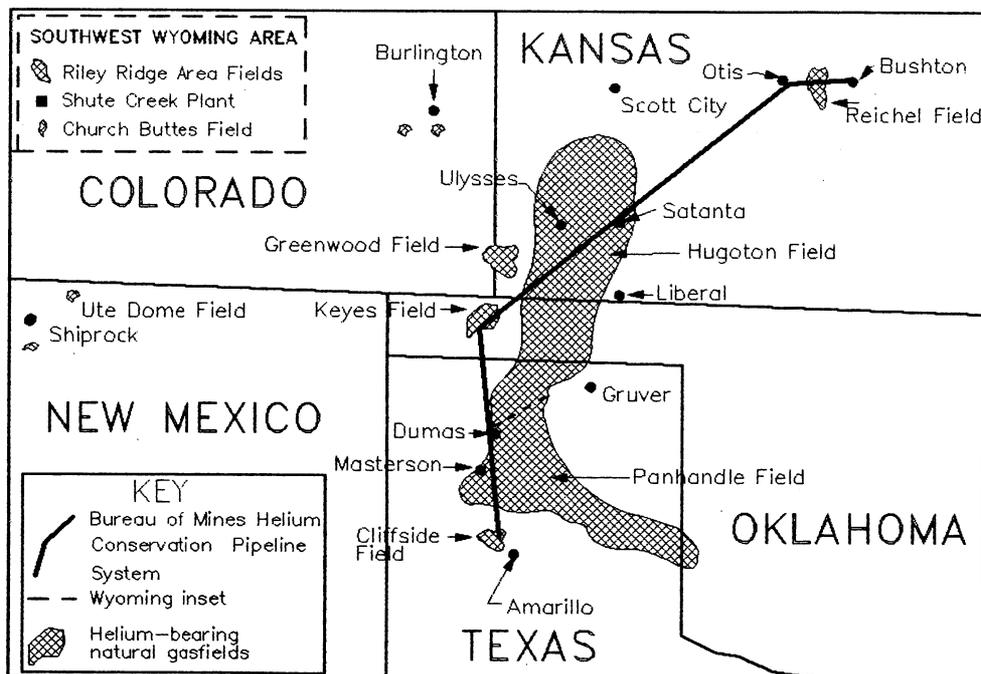
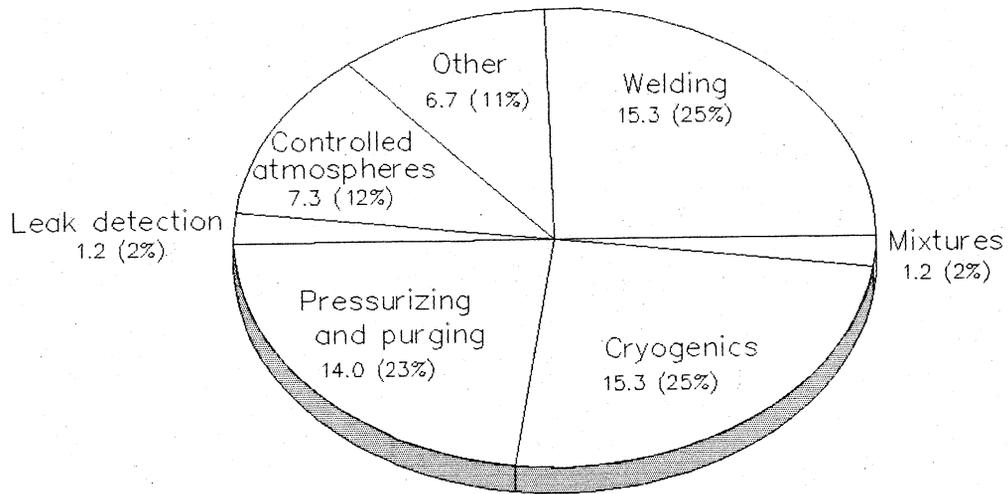


FIGURE 3
ESTIMATED HELIUM CONSUMPTION, BY END USE, IN THE UNITED STATES IN 1991

(Million cubic meters)



Estimated total helium used
(61 million cubic meters)

INDIUM

By Stephen M. Jasinski

Mr. Jasinski, a physical scientist with 5 years of U.S. Bureau of Mines experience, has been the commodity specialist for indium since 1988. Domestic survey data were prepared by Susan Copeland, mineral data assistant.

In the past decade indium usage has been boosted by its increasing importance in high-technology electronics. Indium and its compounds are used in liquid crystal displays, infrared detectors, high-speed transistors, solar cells, and variety of other related applications.

In 1991, the Indium Corporation of America (ICA) and Falconbridge Ltd. joint venture firmly established itself as the leading producer of indium metal in North America and one of the largest in the world. The two companies joined in 1989 and constructed an indium refinery at Falconbridge's Kidd Creek Mine in Timmons, Ontario, Canada. The plant, which is operated by Falconbridge, produces standard-grade (99.97% purity) indium as a byproduct of copper and zinc processing. All indium ingots are shipped to ICA in Utica, NY, the exclusive marketed agent.

Increased refinery production of indium in Canada and France resulted in a slight oversupply situation in the world market in 1991, with world production increasing 20 metric tons over that of 1990. This caused prices to drop slightly throughout the year.

Domestic consumption remained level in 1991, with solders and alloys accounting for about 40% of total usage. The production of indium and indium-tin oxide sputtering targets for use in manufacturing thin film coatings for glass and semiconductors continued to be the most active area of research and development.

DOMESTIC DATA COVERAGE

The two domestic refiners of indium in 1991 chose not to respond to the voluntary survey of indium produced from primary sources. There was no domestic mine production of indium in 1991. Domestic consumption estimates were based upon discussions with the major refiners and consumers and analysis of trade data.

BACKGROUND

Definitions, Grades, and Specifications

Indium is silvery-white in color and has a brilliant metallic luster. It is softer than lead, is very ductile and malleable, and has a very low melting point; therefore, it is well suited for use in solders and low-melting alloys. It retains these plasticlike properties to temperatures near absolute zero. Indium can endure considerable deformation through compression and cold-welds easily.

Some physical constants of pure indium, chemical symbol In, are: atomic number, 49; atomic weight, 114.82; melting point, 156.61° C; boiling point, 2,080° C; and density, 7.31 grams per cubic centimeter at 20° C. Standard grade is 99.97% purity, and high grades are available from 99.99% (4N) to 99.999999% (8N) purity.

Uses and Products for Trade and Industry

Indium was available in various forms, such as ingot, foil, shot, ribbon, wire, and powder. Standard-grade indium was generally used in solders, chemical compounds, plating solutions, and fusible alloys. High-purity indium was used for semiconductors, coatings, and solar cells.

Thin-film coatings on glass, which included indium oxide and indium-tin oxide (ITO), constituted 35% of total domestic indium usage in 1991. Coatings have been the largest area of growth and research for indium in the past 5 years. Applications involving thin coatings on glass can be divided into two categories, electrically conductive and infrared reflecting.

Electrically conductive coatings, the largest group, were used primarily in liquid crystal displays (LCD) for watches, television screens, portable computer screens, video monitors, and other related display devices. Aircraft and locomotive windshields used a transparent, electrically conductive ITO film as a defroster or defogger. In this application, the electric current heats the film quickly to clear the glass. Indium coatings are more effective than other types of materials, but the use of indium was limited because of its higher cost and limited supply. Several automobile manufacturers have also experimented with indium, but because of the cost and availability factors, most have opted for a zinc-silver oxide coating for quick-defrosting windshields. In a similar use, glass doors on commercial refrigerators

and freezers are kept free of condensation and frost by a heated thin film of ITO.

Another group of films includes visually transparent infrared reflecting coatings on window glass, used to control energy losses by reflecting heat inward in winter and outward in summer. For residential windows, the coating is usually applied to a plastic sheet and encased between two panes of glass. This prevents erosion of the coating and reduces the cost of production. Because the expense of refitting a commercial building remains high, other less expensive metals, such as silver, were used instead of indium in coatings on commercial windows.

A major domestic use for indium has been as an addition to bismuth, cadmium, lead, or tin alloys to lower the melting point. These alloys can be used in such applications as electrical fuses, fusible links, or as holding material for the grinding of optical glass. Pure indium and several indium alloys will wet glass and were used for glass-to-metal and glass-to-glass seals.

Indium was used as a strengthening agent for lead solder and as the base material for a variety of low-melting-temperature solders. Many indium-base solders have a melting point below 183° C, the melting point of conventional 63% Sn-37% Pb solder used in electronic applications. This makes indium solder useful for components that would be damaged by a high soldering temperature. Indium-base alloys also remain flexible over a greater temperature range than tin-lead solder. Indium solders reduce the possibility of gold scavenging, a problem that occurs when tin-lead solder is used to join gold components. The solder will gradually leach gold from the contact surface, thus weakening or damaging the soldering joint.

Several manufacturers of pressurized water nuclear reactors used an alloy consisting of 80% silver, 15% indium, and 5% cadmium for nuclear control rods. The production of these rods declined in the United States in the early 1970's when orders for new nuclear powerplants began to drop. Following the Three Mile Island nuclear accident in

1979, all orders for new nuclear powerplants in the United States ceased and subsequent consumption has been only for replacement rods, which must be changed every 15 years.

The use of indium in batteries grew in 1991, as several proprietary indium alloys were used as a replacement for mercury in alkaline batteries. The indium compounds are used for the same purpose as mercury, to prevent the buildup of hydrogen gas in the sealed container, which can cause the battery to leak. Low-mercury batteries were available in AAA, AA, C, D, and 9-volt sizes and did not increase in price.

Minor uses of indium included indium-palladium and indium-gold alloys in dentistry, use as a surface lubricant for abrasive compounds, and as an additive to lubricating oil to prevent corrosion. Certain radiation-detection badges used indium foil because low-energy neutrons easily induce radioactivity in indium.

Industry Structure

ICA, Utica, NY, produces most of its standard-grade indium at the Kidd Creek plant in Timmons, Ontario, Canada, where it is recovered as a byproduct of Falconbridge's Kidd Creek copper-zinc operations. All indium is shipped to the ICA refinery in Utica where it is sold as standard-grade indium or upgraded to higher purity metal. Arconium Specialty Alloys, Providence, RI, refines indium from imported zinc residues, low-grade indium bullion, and indium scrap. Arconium; ICA; Johnson Matthey Electronics, Spokane, WA; and several other companies produce high-purity indium shapes, ingots, and foil. Metalspecialties Inc., Fairfield, CT, intermittently recovers indium from old scrap. New scrap is usually returned to the supplier for reprocessing.

Because indium is primarily recovered from residues, slags, flue dusts, and intermediate compounds resulting from zinc smelting, world mine production is inferred from the average indium content of zinc ore mined. Canada is the largest producer of zinc in the world; therefore,

its mine production is believed to contain the largest quantity of indium.

North America has the world's largest refinery capacity, more than 100 tons per year; however, production was about one-third of the capacity in 1991. Europe and Japan possessed the bulk of the world capacity.

Geology-Resources

Indium occurs predominantly in solid solution in sphalerite (ZnS), the principal mineral of zinc ore, but it often is found in ores of copper, lead, and tin. Indium does not occur in the native state. The average indium content of the Earth's crust is estimated at 0.1 part per million, about the same as that of silver.¹ The indium content of mined zinc deposits ranges from 0 to 100 parts per million. The highest known indium concentrations are in vein, replacement, and contact metasomatic sulfide deposits, especially those containing tin minerals. The indium contents of these tin deposits typically range from 100 to 21,000 parts per million. Deposits of this type include those in the Central City district in Colorado, the Argentine Andes, the Cornwall tin district in England, and the Mount Pleasant deposit in New Brunswick, Canada.

Because indium is usually recovered as a byproduct of zinc, world indium reserves for most countries are based on weighted estimates of the average indium contents of regional zinc ores. For some countries the reserve figure has been based on data provided by the individual country's geologic information agency. (See table 1.)

Technology

A variety of methods are employed to recover indium, depending on the source material and indium content. Indium is primarily recovered as a byproduct of zinc processing. Among the more common methods of recovery are leaching the indium-containing material with sulfuric or hydrochloric acid and extracting the crude indium from solution by cementation on aluminum or zinc

sheets. Solvent extraction with organic solutions is used to recover indium from dilute solutions. Another method involves the precipitation of indium phosphate selectively from slightly acidic solutions and conversion to oxide by leaching in a strong caustic soda solution, followed by reduction of the oxide to metal.

During the smelting of zinc, the indium concentrates in the zinc-lead bottom metal and is separated from that portion by chlorination under molten salt, forming an indium-rich slag. Indium is recovered from the slag by leaching and cementation on zinc or aluminum sheets. The indium deposits on the sheets as a low-density, sponge-like mass, which breaks away and floats to the surface of the solution. The indium sponge is washed, briquetted, melted, and cast into anodes for electrolytic refining.² (See figure 1.)

Recycling.—Spent sputtering targets are returned to the manufacturer for recovery of the indium. Usually the sputtering target consists of indium or indium-tin oxide placed on a copper substrate. After the usable indium surface has been eroded, the remaining material, 20% to 60% of the surface area, depending on the type of target, is returned to the producer to be recycled.

Most indium solder and plating solutions are not recycled. Spent nuclear control rods containing indium are radioactive; therefore, they are buried in nuclear waste disposal sites.

Fusible alloys that are used in applications such as lens blocking, where the alloy is remelted and reused, eventually have to be returned to be realloyed due to contamination and loss.

Byproducts and Coproducts

Indium is a minor byproduct of processing base metal ores or zinc residues. The value of recovered indium is negligible in relation to the value of zinc production. Coproducts include molybdenum, silver, tin, and tungsten.

Substitutes

In solder and fusible alloys, bismuth can substitute for indium, but only for certain applications, because some bismuth-base solders are prone to brittleness. Hafnium can replace silver-indium-cadmium in nuclear control rods. Silver-zinc oxide costs less than indium-tin oxide; therefore, it is preferred for use in automobile windshield coatings for quick defrosting applications.

Economic Factors

Indium, which is classified under Harmonized Code Tariff 8112.91.3000 as "unwrought, waste and scrap, and powders of indium," was imported free from most favored nations (MFN) and subject to a 25% ad valorem duty from non-MFN.

ANNUAL REVIEW

Legislation and Government Programs

The Defense Logistics Agency, which maintains the National Defense Stockpile, proposed reducing the goal for indium in the stockpile 41,990 kilograms to 7,740 kilograms. The inventory on December 31 was zero. Purchases were expected to begin in 1992 at the rate of 1,555 kilograms annually.

Consumption and Uses

Domestic consumption was estimated at 30 tons, and the estimated usage pattern was as follows: solders and alloys, 40%; coatings, 35%; electronic and semiconductor uses, 15%; and research and other, 10%.

Markets and Prices

The price for standard-grade indium began the year at \$225 per kilogram and dropped in July to \$210 per kilogram, where it remained until the end of the year. The price quoted for other producers was slightly higher. The oversupply of indium worldwide caused the price to drop slightly during the year.

Foreign Trade

U.S. imports for consumption from Canada increased from 11% of the total in 1990 to 60% in 1991. This was because of the opening of the Kidd Creek indium plant in Ontario by ICA and Falconbridge. All indium refined at the plant was sold through the ICA sales office in Utica, NY. (See table 2 and figure 2.)

World Review

World indium production in 1991 was estimated at 140 tons, an increase of 20 tons from 1990. The increase was attributed to the opening of the Kidd Creek facility in Canada and greater output from Metaleurope in France. World consumption was estimated at between 120 to 130 tons. The world indium market was in a slight oversupply situation as the leveling off of new uses for indium and the world economic recession slowed the quick growth the indium market had experienced in the late 1980's.

Capacity.—The data in table 3 are the rated annual capacity for refineries as of December 31, 1991. Rated capacity is defined as the maximum quantity of material that can be produced in a given period on a normally sustainable long-term operating rate. It is based on the physical equipment of the plant and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that in the judgment of the author can be brought into production within a short period with minimum capital expenditure.

Refinery capacities for indium are based on the combination of data on engineering capacity provided by some companies and estimates by the U.S. Bureau of Mines. (See table 3.)

Canada.—NovaGold Resources of Halifax, Nova Scotia, signed a letter of intent to purchase the Mount Pleasant tin-

tungsten mine in New Brunswick from Lac Minerals Ltd. The Mount Pleasant property was opened as a tungsten mine in 1983, but it was closed in 1985 due to the depressed tungsten market. The property has substantial reserves of tin, tungsten, and molybdenum. Mount Pleasant also has one of the largest reserves of indium in the world.

NovaGold intends to recover tin as the primary metal and bismuth and indium as coproducts. Because of the recent trend of low tin prices, NovaGold plans to use the value of indium production to enhance revenue. The sale was expected to be final in 1992.

The Falconbridge-ICA plant in Timmons, Ontario, completed its first full year of operation in 1991, and it was the largest producer in North America. The estimated output was about 25 tons. Refinery capacity was 30 tons per year, but the plant is expected to adjust output to demand patterns.

Cominco Ltd. produced indium at its Trail, British Columbia, refinery from domestic and imported materials. The plant operated at less than 50% capacity because of the slow market conditions. Cominco sold its indium primarily outside of North America.

Japan.—Japan consumed about 66 tons of indium in 1991, a slight increase from that of 1990. About 40% of that went into the production of thin-film coatings. Domestic refinery output was estimated at 30 tons, with imports supplying the balance of market requirements. The Geological Survey of Japan began a study of the world's indium deposits in 1991 and collected samples from the Mount Pleasant site in Canada, the Toshama deposit in India, and the Akenobe, Goka, and Toyoha Mines in Japan.

OUTLOOK

World reserves and increases in production capacity are sufficient to meet expected demand for indium through the year 2000. Consumption of indium is expected to increase gradually in this period, especially for LCD's semiconductor materials, batteries, and in

low-temperature solder for military and commercial electronics. Other uses such as nuclear control rods, which have a lifespan of 15 years, and fusible alloys should remain steady.

¹Hurlbut, C. S., Jr., and C. Klein. *Manual of Mineralogy*. Wiley, 19th ed., 1977, pp. 123-124.

²Stevens, L. G., and C. E. T. White. *Indium and Bismuth*. Ch. in *Metals Handbook*. ASM Int. 10th ed., v. 2, 1990, p. 750.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Indium. Ch. in *Mineral Commodity Summaries*, annual.

Other Sources

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Canadian Mining Journal.

Engineering and Mining Journal.

Metal Bulletin (London).

Metals Week.

Mining Journal (London).

Roskill Information Services Ltd. (London).

TABLE 1
ESTIMATED WORLD INDIUM
RESERVES, 1991

(Metric tons)

Continent and country	Reserves	Reserve base
Africa	NA	25
Asia:		
China	200	500
Japan	70	150
Total	270	650
Australia	NA	50
Europe:		
Belgium	(¹)	(¹)
France	(¹)	(¹)
Germany	50	100
Italy	(¹)	(¹)
U.S.S.R.	200	300
Total	950	1,500
North America:		
Canada	600	1,500
United States	300	600
Total	900	2,100
South America:		
Bolivia	NA	25
Peru	100	150
Total	100	175
World total	2,220	4,500

NA Not available.

¹Belgium, France, and Italy are combined; included in "Europe: Total."

TABLE 2
U.S. IMPORTS FOR CONSUMPTION OF INDIUM, BY CLASS AND COUNTRY

Class and country	1989		1990		1991	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Unwrought and waste and scrap:						
Belgium	6,035	\$2,544	5,470	\$1,146	2,780	\$565
Canada	357	105	3,398	788	21,924	4,849
China	2,444	629	3,390	734	—	—
France	4,629	1,324	5,675	1,080	4,862	1,009
Germany, Federal Republic of	2,931	485	110	33	2	2
Hong Kong	44	12	—	—	—	—
Italy	2,150	604	3,347	717	1,598	290
Japan	659	500	380	197	427	141
Netherlands	1,109	313	299	80	185	55
Peru	914	492	1,927	392	—	—
U.S.S.R.	529	135	—	—	—	—
United Kingdom	5,012	1,801	6,162	1,387	4,510	956
Total	26,813	8,944	30,158	6,555	36,288	7,867

'Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 3
ESTIMATED WORLD INDIUM
PRIMARY REFINERY
PRODUCTION AND CAPACITY,
DECEMBER 31, 1991

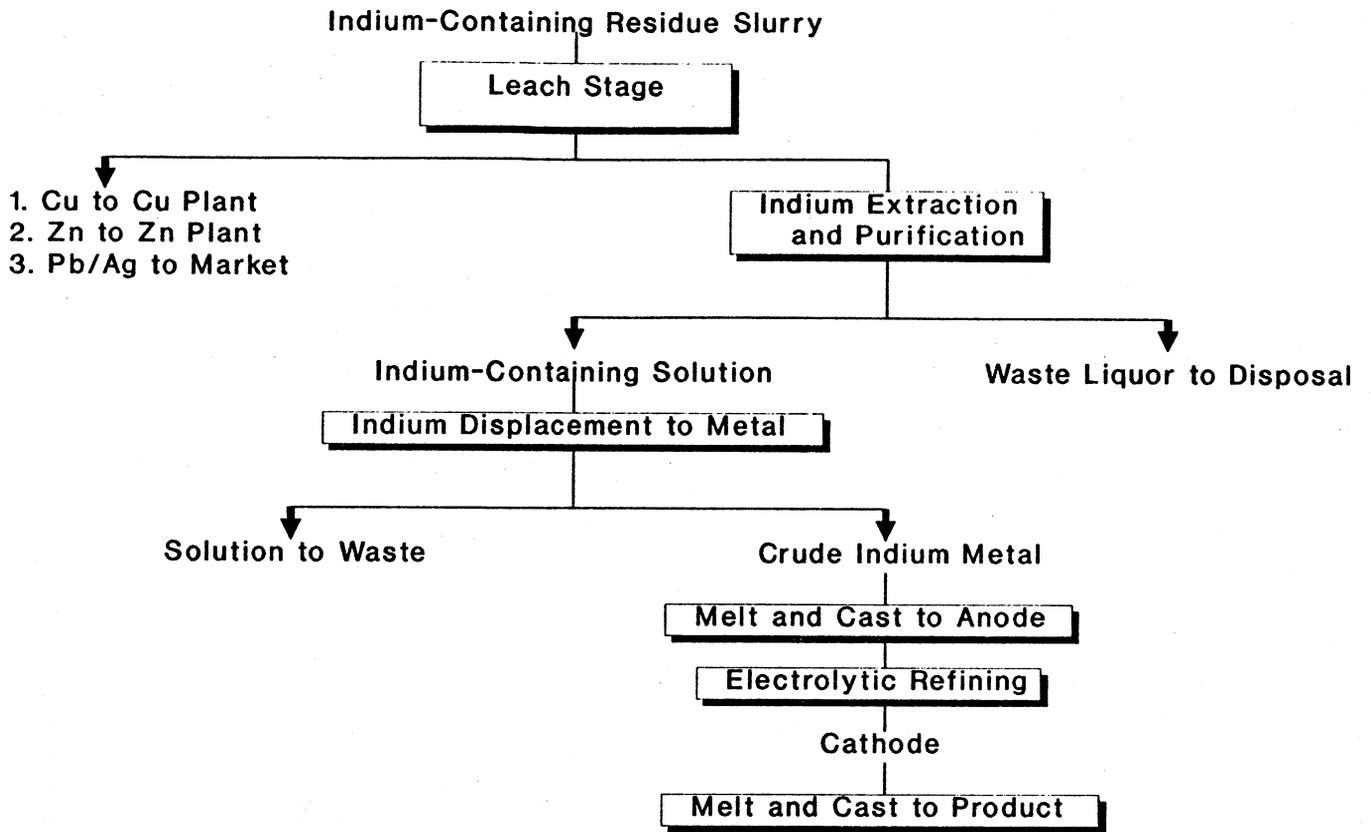
(Metric tons)

	Production	Capacity
Belgium	20	25
Canada	30	70
China	12	20
France	25	35
Germany	2	10
Italy	150	10
Japan	30	60
Netherlands	1	30
Peru	2	6
U.S.S.R.	3	15
United Kingdom	—	6
United States	NA	40
Total	140	300

NA Not available.

'Excludes U.S. production.

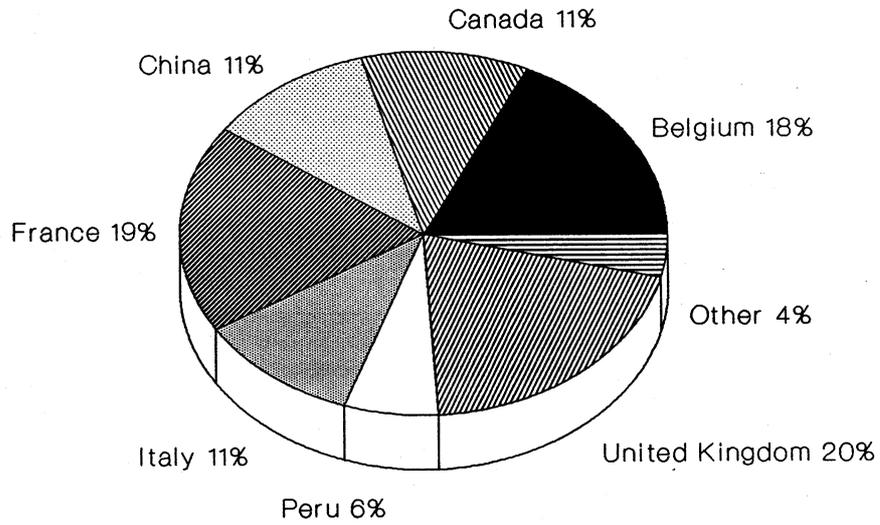
FIGURE 1
INDIUM PLANT PROCESSING CYCLE



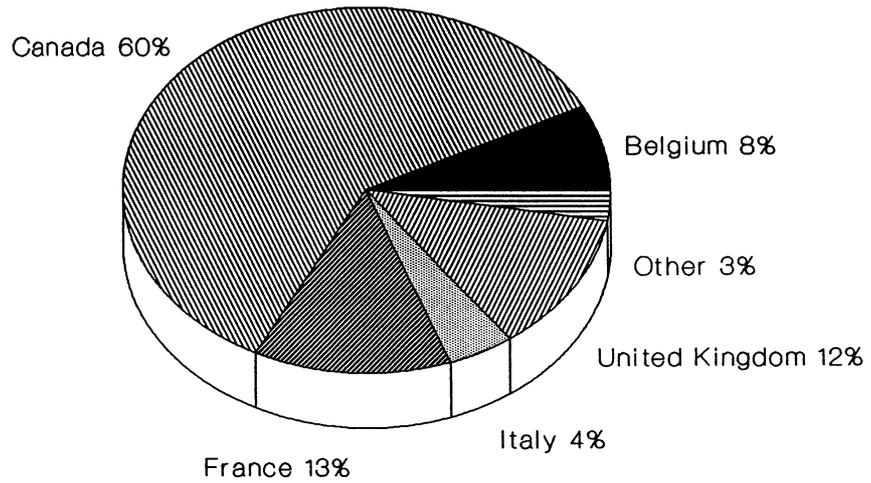
Source: Indium Corp. of America.

FIGURE 2
U.S. IMPORT SOURCES OF INDIUM 1990-91

1990



1991



Source: Bureau of the Census.

IODINE

By Phyllis A. Lyday

Mrs. Lyday, a physical scientist with the U.S. Bureau of Mines, has been the commodity specialist for iodine for 13 years. Domestic survey data were prepared by Blanche Hughes, statistical assistant; and international data tables were prepared by William L. Zajac, Chief, Section of International Data.

Three producers of crude iodine supplied approximately 62% of domestic demand; the remainder was imported. Because some exports and imports are in product categories rather than crude products, net imports are not clearly developed. The major world producer, Japan, produced iodine from brines associated with gas production. The second largest producer, Chile, produced iodine as a coproduct of sodium nitrate.

DOMESTIC DATA COVERAGE

Domestic production data for iodine are developed by the U.S. Bureau of Mines from a voluntary survey of U.S. operations. Of the four operations to which a survey request was sent, four responded, representing an estimated 100% of the total production shown in tables 1 and 8. (See tables 1 and 8.)

BACKGROUND

Definitions, Grades, and Specifications

Commercial crude iodine normally has a minimum purity of 99.5%. Resublimed iodine is usually 99.9% pure. Most iodine is converted for industrial use to potassium iodide, sodium iodide, and other inorganic compounds, as well as numerous organic compounds.

Geology-Resources

Iodine occurs in rocks and soils, surface and underground brines, and caliche ores. Michigan brines contain

about 30 parts per million (ppm) of iodine in the Sylvania Formation of Devonian age. California brines contain 30 to 70 ppm of iodine in brines associated with oilfields in the middle Miocene age, Monterey Formation, and the lower Pliocene age Repetto Formation. Louisiana brines contain about 35 ppm of iodine. In Oklahoma, iodine concentrations associated with oil and gas range between 150 and 1,200 ppm. In Woodward County, OK, iodine occurs in the Morrowan Formation of Pennsylvania age. The iodine concentration averages about 300 to 350 milligrams per liter; 22 barrels of brines are required for each kilogram of iodine.

Extensive iodine-bearing nitrate ores occur in caliche deposits in a belt several hundred kilometers long in the Atacama Desert of northern Chile. The ore layers are 1 to 3 meters thick, usually flat or gently dipping and near the surface. Evaporate minerals such as lautarite (CaI_2O_6) and dietzeite ($2\text{CaO}\cdot\text{I}_2\text{O}_5\cdot\text{CrO}_3$) occur as cementing material in unconsolidated surface material or as veins and impregnations in bedrock.

Japanese brines contain 50 to 135 ppm of iodine in the Kiwada, Otadai, and Umegase Formations of the Kazusa Group of Pliocene age. The major iodine-producing area was the southern Kanto Gasfield, which extends over Chiba, Tokyo, and Kanagawa Prefectures. Iodine was produced in the Niigata and Nakojo Gasfields in Niigata Prefecture, on the Sea of Japan side of central Japan, and the Sadowara Gasfield in Miyazaki Prefecture, southern Kyushu.

In Indonesia, iodine occurs with trace amounts of bromine in brines associated with oil. The most important iodine-producing area is the Gujangan anticline of sandstone and diatomaceous marls of the Upper Pliocene, Kailiberg Formation.

On Okinawa, iodine occurs in concentrations of about 85 ppm in the Tomigusuku Formation of the Shimajiri Group of late Miocene-early Pleistocene age.

Technology

Processing.—In Japan and the United States, iodine is removed from brines by processes that separate the brines from any associated hydrocarbons. In the blowing-out process, brine is acidified and iodine is liberated by reducing the pH to about 3. A countercurrent stream of air transports the liberated iodine to a second tower in which the iodine is absorbed by a solution of hydriodic acid. The iodine settles, is filtered, and melted under concentrated acid. Brine stripped of iodine is treated and then reinjected into its subsurface formation of origin.

In the absorption process, brine is passed through an absorber, and the waste brine is neutralized and sent to a disposal well. The absorbent laden with iodine is treated with an alkaline solution to regenerate the absorbent and eludes iodine as sodium iodide. Iodide is precipitated under acid.

Japanese plants also use an ion-exchange resin. Upon saturation, the iodine is eluted using a caustic solution that regenerates the resin. Iodine is then

processed with a sodium chloride solution and melted under acid.

Chilean caliche deposits are mined by open pit methods. The ore is leached with an alkaline solution to dissolve the iodine as sodium iodate, which is converted to sodium iodide. Iodine is precipitated by reacting with additional alkaline solution. The precipitated iodine is filtered in bag filters and the iodine free-leach solution is returned to the nitrate-leaching cycle.

Recycling.—The removal of ionic silver from photographic processing solutions, such as developer, fixer, bleach fixers, and washwaters, can be accomplished with halogens such as iodine and an adsorbent. Photographic silver is commonly recovered by electrolytic methods if the concentration is greater than 500 ppm. Adsorbents such as natural and synthetic zeolites, activated alumina, activated silica, Fuller's earth, and ion exchange resins are used to recover low concentrations of silver from a stream.

Economic Factors

Prices.—Changes in the official price of crude iodine have in the past been initiated during shortages. Because iodine cannot be substituted in radiopaque, animal feeds, catalysts, and stabilizers readily, shortages tend to cause the accumulation of inventories to ensure an adequate supply. An adequate supply tends to lower and stabilize the price. (See table 2.)

Costs.—One typical iodine brine well costs about \$2 million to complete and is between 1,800 and 3,000 meters deep. Electrical costs for maintaining the pumps to bring the brine to the surface, for air-blowing the iodine, and for reinjecting the brine are major components of maintenance costs. Capital costs have been estimated at \$20 per pound of annual iodine production. These costs include high-quality stainless steels because iodine is highly corrosive. In addition, the brine must be leased from

private landowners over large acreage for many years. The principal material cost is for chlorine because 1 pound is required for every 1.4 to 1.8 pounds of iodine produced.

Tariffs.—Crude and resublimed iodine enter the United States duty free. Calcium and cuprous iodine has a 25% ad valorem for non-most-favored-nation status. Potassium iodide has a 2.8% ad valorem for most-favored-nation status and 7.5% ad valorem for non-most-favored-nation status.

Depletion Provisions.—The domestic and foreign depletion allowances for mined iodine are 14% of gross income, and they may not exceed 50% of net income without the depletion deduction. The domestic and foreign depletion allowances for minerals from brine wells are 5%.

Operating Factors

Environmental Requirements.—The reinjection of waste brine is a limiting factor to the production of iodine. During 1982, the Environmental Protection Agency reclassified disposal wells for spent brine after halogen extraction as Class 5 wells. All of the reinjection wells for iodine in Oklahoma were drilled for the reinjection of waste associated with brine production or oil and gas effluent.

Toxicity.—Iodine is absorbed by the body and concentrated in the thyroid. Iodine is essential to higher animals and humans. A normal person requires about 75 milligrams of iodine per year, which is usually consumed as iodized salt that contains one part sodium or potassium iodide to 100,000 parts of sodium chloride. Iodine deficiency is a major cause of goiter.

The maximum safe concentration for short-term air environment exposure of up to 1 hour is 1.0 ppm. Exposure of the lungs and eyes can be irritating at concentrations of 0.1 ppm and should be avoided. Greater exposure can cause

severe irritations to the eyes and the respiratory tract and may lead to pulmonary edema.

In 1979 and 1986, nuclear accidents caused the release of radioactive iodine, I^{131} , into the atmosphere. A dosage of potassium iodide (KI) administered before or shortly after exposure of radioactive iodine can block the intake of radiation to the thyroid. The dosage must be repeated if exposure continues. Replenishing the thyroid with KI prevents the thyroid from using radioactive I^{131} for normal metabolic needs.

ANNUAL REVIEW

Legislation and Government Programs

The Food and Drug Administration (FDA) announced the expiration of the provisional listing for FDA Red Dye No. 3 containing 58% iodine by weight. Uncertified material is commonly called erythrosine or other names, including Color Index (C.I.) Acid Red 51 and C.I. Food Red 14. FDA Red No. 3 is a bluish red color of the xanthene class and is currently identified in Chemical Abstracts as CAS Reg. No. 16423-68-0. The common name established by industry is fluorescein. The effective date of the expiration was January 29, 1990, for the use of Red No. 3 in coloring cosmetics and externally applied drugs and for all uses of the lakes. Lakes are soluble dyes absorbed on or combined with an inorganic carrier. Red No. 3 continued to be used in food additives.

Strategic Considerations

The National Defense Stockpile contained 6.1 million pounds of crude iodine. The stockpile goal remained at 2.6 million kilograms (kg) (5.8 million pounds). The Defense Logistics Agency (DLA) of the U.S. Department of Defense disposed of 35,634 kg of excess material valued at \$124,772 during fiscal year 1991. The DLA sought to barter surplus metals and minerals, including iodine, but no exchanges were reported.

Production

IoChem Corp. began production in 1987, 2 miles east of Vici, Dewey County, OK, by the blowing-out process. The majority of production was shipped to Schering AG, Federal Republic of Germany, under a long-term contract. IoChem was reported to have nine production wells and four injection wells with a total production capacity of 1,400 kg.

North American Brine Resources began operation of a miniplant at Dover in Kingfisher County, OK, in 1983. The plant is at an oilfield reinjection disposal site that obtains brines from about 50 wells in the Oswego Formation. Iodine concentrations ranged up to 1,200 ppm. The company also operated a plant at the border of Woodward and Harper Counties, OK, that began operating in 1991.

Woodward Iodine Corp. began production in 1977 and was purchased by Asahi Glass Co. of Japan in 1984. Woodward operated a plant in Woodward County that produced iodine from 14 brine wells using the blowing-out process. Nameplate capacity was reported at 900,000 kg per year.

Consumption and Uses

Iodine was used primarily in animal feed supplements, catalysts, inks and colorants, pharmaceuticals, photographic equipment, sanitary and industrial disinfectants, stabilizers, and radiopaque medium. Other smaller uses included production of batteries, high-purity metals, motor fuels, iodized salt, and lubricants.

The lithium-iodine battery was the first commercially successful lithium battery and is unusual because of its in situ growth of electrolytes. Superior charge transfer is achieved using an iodine compound with powdered iodine. Layers of lithium iodide act as both electrolyte and separator and are self-sealing in the event of a crack. Thus, the batteries are intrinsically reliable and withstand abuse.

Mallinckrodt Medical Inc., a division of Mallinckrodt Inc., was restructured

into a separate corporation in July 1990. Mallinckrodt Medical ranks as one of the world's leading medical products companies, organized in five divisions: anesthesiology, cardiology, nuclear medicine, radiology, and sensor systems. The company pioneered many advances in the development of X-ray contrast media and later nuclear medicine products for use in diagnostic procedures. The company produces a range of X-ray contrast media and nuclear medicine pharmaceuticals using iodine to visualize the body's organs and blood vessels.¹ Optiray, a nonionic X-ray contrast medium, was introduced in 1989 and will be expanded to several European countries. The conventional ionic segment was distributed under the brand name of Conray and Hexabrix for marketing in several countries.² Aided by a \$75 million investment, output was being doubled at St. Louis, MO.

Sterling Drug, a unit of Eastman Kodak, announced a worldwide pharmaceutical and consumer health alliance with Sanofi of French Elf Aquitaine. Omnipaque was offered by a licensing arrangement from Norwegian patent holder Hafslund Nycomed to Winthrop Pharmaceutical.

Clinical trials reached phase 2 in the United States for Hafslund Nycomed's Iodixanol nonionic X-ray contrast medium. The medium, described as third generation, is the first of its kind approved for general use.³

Bristol-Myers Squibb offered Isovue, the U.S. market leader among nonionics, to the Italian Bracco Industria Chimica. United-Guardian Inc. granted Columbia Laboratories Inc. of Hollywood, FL, an exclusive option on an iodoform-based antiseptic stick. The stick is reported not to stain, sting, or burn and can be carried in a pocket or purse.⁴

Eastman Chemical Co. completed a \$200 million expansion of its chemicals from coal complex in Kingsport, TN. The expansion will increase the production of acetic anhydride made from coal by 560 million pounds to 1.2 billion pounds per year.⁵ Eastman is one of two companies that produce acetic anhydride, the other being Hoechst Celanese with

270,000 pounds of production per year at three plants in three States. About 80% of acetic anhydride is used to produce cellulose acetate.⁶

Tall oil capacity increased as capacity was expanded to 920,000 tons per year of fractionation capacity. Westvaco boosted capacity at Charleston Heights, SC, by 10,000 tons in 1990 and at De Ridder, LA, by 25,000 tons in 1991. Iodine is used to stabilize the tall oil for use in various tall oil fatty acids and tall oil rosin that compete against other types of oils for use in polymers. The supply of crude tall oil is increasing due to additional pine pulp production.⁷ (See table 3.)

Prices

The average declared c.i.f. value for imported crude iodine was \$10.16 per kg (\$4.61 per pound). The average declared c.i.f. value for imported crude iodine from Japan averaged \$9.89 per kg (\$4.49 per pound). The average declared c.i.f. value for iodine imported from Chile was \$10.38 per kg (\$4.71 per pound). Quoted yearend U.S. prices for iodine and its primary compounds are shown in table 4. (See table 4.)

Foreign Trade

The U.S. Government adopted the Harmonized Commodity Description and Coding System (Harmonized System) as the basis for its export and import tariff and statistical classification systems. The system is intended for multinational use as a basis for classifying commodities in international trade for tariff, statistical, and transportation purposes. The Harmonized System as proposed includes resublimed and crude iodine under the same code, and the duty rate is free. Values that differ significantly could be a result of items being placed in the wrong category. (See tables 5 and 6.)

World Review

Capacity.—The data in table 7 are rated capacity for plants as of December 31,

1991. Mine capacity for iodine is based on rated capacity as reported by the company, another government agency, or another published source.

Chile.—Sociedad Química y Minera de Chile (SQM, formerly known as SOQUIMICH) was the largest producer of iodine in Chile. Production capacity at the Maria Elena plant was raised from 230,000 to 430,000 metric tons per year. Investment of about \$2 million has involved the expansion of solar evaporation ponds and process modification. Installed capacity was reported at 6,000 tons per year, although current production was about 4,000 tons per year.⁸ SQM also announced plans to be certified under the International Organization for Standardization (ISO) 9000 program, which calls for third-party quality-assurance registration of a manufacturer's facility, process, and product lines. It places particular emphasis on documentation and uniformity of process.⁹

Cominac S.A., a subsidiary of Inversiones Errazuriz S.A. Enterprises, began production at two of three reserve areas of the Pozo Almonte project. The site is situated in a valley where the natural gravity flow is utilized to collect the iodine-rich solutions. A third reserve area was undergoing a third step in a civil process to determine ownership. The two areas under development are not involved in the civil processing and are under development by a subsidiary company, Compania de Salitre y Yodo de Chile (Cosayach). Cosayach has a plant to recover 600 metric tons of iodine per year by heap leaching. Plans to expand capacity were being developed.

ACF Minera Ltda., is a Chilean company with 50% joint venture with DSM of the Netherlands. The company maintains three production facilities that have a nameplate capacity of 1,200 metric tons and are located in the first region of Chile at La Granja, Lagunas, and Iris. The facilities are about 100 miles southeast of the port city of Iquique. The production capacity was reported to be 810 metric tons of 99.5% to 100.5% iodine, with mineral reserves

of 48,000 metric tons of iodine in situ. The company also owns mineral rights at other locations in the first and the second regions of Chile.¹⁰

Indonesia.—The only producer of crude iodine was the state-owned pharmaceutical firm, P. T. Kimia Farma, that operated a plant at Watudakon near Mojokerto, East Java.

Japan.—Production of iodine was from underground brines associated with natural gas. Japan was the world's leading producer of iodine in 1989. Six companies operated 17 plants with a total production capacity of 9 million kg per year.

Mallinckrodt announced a 10-year exclusive agreement with Yamanouchi Pharmaceutical for distribution of Optiray in Japan. (See table 8.)

Current Research

A radioiodine-labeled tracer for studying receptors in the brain may be particularly useful in studying disorders such as Parkinson's disease. Researchers describe the high affinity that the tracers have for dopamine sites involved with Parkinson's disease. Parkinson's is thought to be caused by the degeneration of a set of neurons in the brain that use dopamine as a neurotransmitter.¹¹

Researchers at Los Alamos National Laboratory are working on a semiconductor material that could convert sunlight into electrical or chemical energy. Semiconductor crystals of platinum linked with halogens such as iodine form the basis of the mixed-halide chains. The material has tremendous chemical flexibility. The unusual feature of the mixed-crystal is that the electron remains in the high-energy state after the light source is removed, thus providing a mechanism for storing electrical energy.¹²

An iodine compound was used to synthesize gilvocarcin M, a class of natural products. Gilvocarcin M is one of a growing class of compounds that has been isolated from bacteria. The compounds share a common aromatic

ring system to which various rare sugars are attached through a carbon bond. The compounds are being studied as potential anticancer, antiviral, and antibiotic drugs.¹³

OUTLOOK

Iodine production capacity in the United States and Chile has doubled during the past decade, ensuring an adequate world supply. Uses for iodine in specialty chemicals have remained stable. Recent developments in digital images using computers can produce electronic prints and overhead transparencies without using processing. Using a digital camera, or scanning and film and converting to digital, images are produced using pixels or numerical by position and color and stored on hard drives, disks, tape, or optical storage. Future use of iodine in films and processing could be limited to specialty imaging in the next decade.¹⁴

¹Chemical Marketing Reporter. Mallinckrodt Medical Launches New Corporate Identity Program. V. 240, No. 11, 1991, p. 25.

²———. Mallinckrodt Introduces a Diagnostic. V. 240, No. 4, 1991, p. 14.

³European Chemical News. Iodixanol Filing. V. 57, No. 1517, 1992, p. 23.

⁴Chemical Marketing Reporter. Iodine Stick License. V. 240, No. 4, 1991, p. 7.

⁵———. Eastman Coal Chemical Expanded at Kingsport. V. 240, No. 19, 1991, p. 5.

⁶———. Chemical Profile-Acetic Anhydride. V. 241, No. 12, 1992, p. 42.

⁷———. Chemical Profile-Tall Oil. V. 240, No. 23, 1991, p. 46.

⁸Industrial Minerals (London). Chile-SQM Potassium Nitrate Expansion Underway. No. 282, 1991, p. 9.

⁹Shon, M. Drugs & Fine Chemicals-Iodine Pricing Stable; Demand Improving in '92. Chem. Marketing Rept., v. 241, No. 8, 1992, p. 16.

¹⁰Barrows, A. (Santiago, Chile). Written communication; available upon request from P. A. Lyday, U.S. BuMines, Washington, DC.

¹¹Dagani, R. Cocaine Analog for Parkinsonism Studies. Chem. & Eng. News., v. 69, No. 41, 1991, pp. 25, 26.

¹²Gustafson, J. Los Alamos Sheds Light on Crystal Matter. Leading Edge (London). No. 24, 1991, p. 11.

¹³Borman, S. Gilvocarcin M Synthesis Wins Praise for Elegance. Chem. & Eng. News. v. 70, No. 19, 1992, pp. 56, 58.

¹⁴NcNamara, M. J., and L. White. Photograph Computes. Popular Photography. v. 99, No. 7, 1992, pp. 46-53.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Iodine. Ch. in Mineral Facts and Problems, 1985.

Iodine. Ch. in Minerals Yearbook, annual.

**TABLE 1
SALIENT IODINE STATISTICS**

(Thousand kilograms and thousand dollars)

	1987	1988	1989	1990	1991
United States:					
Production	W	1,015	1,508	1,973	1,999
Imports for consumption ¹	3,200	3,300	3,326	3,168	3,555
Exports ¹	NA	NA	NA	2,100	1,462
Consumption:²					
Apparent	3,200	4,315	4,834	3,041	4,092
Reported	2,630	2,900	2,900	3,100	3,200
Price, average c.i.f. value, dollars per kilogram	\$15.26	\$17.46	\$19.50	\$13.78	\$10.16
World: Production	¹ 12,671	¹ 14,607	¹ 15,977	¹ 16,114	² 16,159

¹Preliminary. Revised. NA Not available. W Withheld to avoid disclosing company proprietary data.

¹Bureau of the Census.

²Calculated by production plus imports minus exports.

TABLE 2
TIME-PRICE RELATIONSHIPS FOR CRUDE IODINE

Year	Average annual c.i.f. value, dollars per pound		Average annual c.i.f. value, dollars per kilogram	
	Actual price	Based on constant 1991 dollars	Actual price	Based on constant 1991 dollars
1970	1.10	3.60	5.59	17.50
1971	1.58	4.68	3.48	10.32
1972	1.64	4.64	3.62	10.22
1973	1.72	4.57	3.79	10.07
1974	1.86	4.53	4.10	9.99
1975	2.21	4.90	4.87	10.80
1976	2.13	4.44	4.70	9.79
1977	1.05	2.05	2.31	4.52
1978	2.21	4.03	4.87	8.87
1979	3.37	5.64	7.43	12.43
1980	4.72	7.24	10.41	15.97
1981	6.03	8.44	13.29	18.60
1982	5.97	7.85	13.16	17.31
1983	5.57	7.05	12.28	15.54
1984	4.90	5.98	10.80	13.19
1985	5.38	6.38	11.86	14.06
1986	5.68	6.56	12.52	14.47
1987	6.92	7.75	15.26	17.09
1988	7.92	8.59	17.46	18.93
1989	7.70	8.02	16.98	17.67
1990	6.26	6.26	13.80	13.80
1991	4.61	4.61	10.15	10.15

Source: Bureau of the Census.

TABLE 3
U.S. CONSUMPTION OF CRUDE IODINE, BY PRODUCT

Product	1990		1991	
	Number of plants	Consumption (thousand kilograms)	Number of plants	Consumption (thousand kilograms)
Reported consumption:				
Resublimed iodine	7	143	9	127
Hydriodic acid	2	W	1	W
Calcium iodate	(¹)	(¹)	(¹)	(¹)
Calcium iodide	3	110	3	113
Cuprous iodide	3	17	3	24
Potassium iodide	5	627	5	643
Potassium iodate	4	62	3	42
Sodium iodide	4	81	6	66
Other inorganic compounds	15	1,133	16	1,191
Ethylenediamine dihydroiodide	4	433	4	494
Other organic compounds	8	448	6	476
Total	² 30	3,054	² 29	3,176
Apparent consumption	XX	5.3	XX	5.2

W Withheld to avoid disclosing individual company proprietary data; included with "Other inorganic compounds." XX Not applicable.

¹Included with calcium iodide.

²Nonadditive total because some plants produce more than one product.

TABLE 4
YEAREND 1991 PUBLISHED PRICES OF ELEMENTAL IODINE AND SELECTED COMPOUNDS

	Dollars per kilogram ¹	Dollars per pound ¹
Calcium iodate, FCC drums, f.o.b. works	\$16.42	\$7.45
Calcium iodide, 50-kilogram drums, f.o.b. works	23.65- 25.65	11.62- 12.07
Hydrodic acid, f.o.b. works	18.19- 19.95	8.25- 9.05
Iodine, crude, drums	11.50- 13.50	5.21- 6.12
Potassium iodide, U.S.P., drums, 5,000-pound lots, delivered	26.48	12.01
Iodine, U.S.P.	17.00	7.70
Sodium iodide, U.S.P., crystals, 5,000-pound lots, drums, freight equalized	36.38	16.50

¹Conditions of final preparation, transportation, quantities, and qualities not stated are subject to negotiations and/or somewhat different price quotations.

Source: Chemical Marketing Reporter. V. 240, No. 27, Dec. 31, 1991, pp. 35-40.

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF CRUDE IODINE, BY TYPE
AND COUNTRY

(Thousand kilograms and thousand dollars)

Country	1990		1991	
	Quantity	Value ¹	Quantity	Value ¹
Iodine, crude:				
Chile	1,321	18,598	1,798	18,653
Germany	—	—	(²)	11
Italy	(²)	53	(²)	45
Japan	1,798	24,295	1,705	16,863
Mexico	20	307	—	—
Netherlands	—	—	(²)	9
United Kingdom	(²)	2	(²)	14
Total³	3,139	43,256	3,503	35,594
Iodine, potassium:				
Canada	—	—	2	26
Germany	(²)	4	(²)	5
India	17	215	37	400
Italy	9	23	9	26
Japan	1	18	—	—
Netherlands	—	—	(²)	7
Switzerland	—	—	2	8
United Kingdom	2	37	2	30
Total	29	297	52	502
Grand total	3,168	43,553	3,555	36,096

¹Declared c.i.f. valuation.

²Less than 1/2 unit.

³Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 6
U.S. EXPORTS OF CRUDE IODINE
IN 1991, BY TYPE AND COUNTRY

(Thousand kilograms and thousand dollars)

Country	Quantity	Value ¹
Iodine, crude:		
Canada	66	981
China	34	344
Dominican Republic	146	33
Germany	455	5,019
India	17	165
Japan	281	2,795
Mexico	204	4,526
Taiwan	22	258
United Kingdom	95	1,144
Venezuela	10	84
Other ²	28	435
Total	1,358	15,784
Iodide, potassium:		
Canada	30	26
Mexico	17	48
Netherlands	25	127
Taiwan	14	23
Other ³	19	174
Total	105	398
Grand total	1,463	16,182

¹Declared c.i.f. valuation.

²Includes United Arab Emirate, Australia, the Bahamas, Columbia, France, Ghana, Ireland, Italy, the Republic of Korea, Panama, Peru, Salvador, and Spain.

³Includes Chile, Finland, Hong Kong, Ireland, the Republic of Korea, Saudi Arabia, Spain, and Sweden.

Source: Bureau of the Census.

TABLE 7
**WORLD IODINE ANNUAL
 PRODUCTION CAPACITY,¹
 DECEMBER 31, 1991, RATED
 CAPACITY²**

(Thousand kilograms)

Country	Capacity
North America: United States	1,200
South America: Chile	3,800
Europe: U.S.S.R.	2,000
Asia:	
China	500
Indonesia	4
Japan	7,000
Total	7,600
World total	³ 15,000

¹Actual capacity limited by brine supply.

²Includes capacity at operating plants as well as at plants on standby basis.

³Data do not add to total shown because of independent rounding.

TABLE 8
CRUDE IODINE: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991 ³
Chile	⁴ 3,149	⁴ 3,631	⁴ 4,363	⁴ 4,100	4,300
China ⁴	500	500	500	500	500
Indonesia	8	10	14	⁵ 60	60
Japan	7,014	7,451	7,592	⁵ 7,581	7,500
U.S.S.R. ⁴	2,000	2,000	2,000	⁵ 1,900	1,800
United States	W	⁵ 1,015	1,508	1,973	⁵ 1,999
Total	⁴ 12,671	⁴ 14,607	⁴ 15,977	⁴ 16,114	16,159

⁴Estimated. ⁵Revised. W Withheld to avoid disclosing company proprietary data.

¹Table includes data available through June 8, 1992.

²In addition to the countries listed, New Zealand also produces elemental iodine, but data are not available, and available information is inadequate for formulation of reliable estimates of output levels.

³Reported figure.

⁴Excludes U.S. production.

IRON ORE

By William S. Kirk

Mr. Kirk became the commodity specialist for iron ore in 1992, and was previously responsible for cobalt, depleted uranium, hafnium, nickel, radium, thorium, and zirconium. The domestic survey data were compiled by Robin C. Kaiser, statistical assistant, Branch of Data Collection, and Henry F. Sattlelight, management analyst. The world production table was prepared by William L. Zajac, Chief, International Data Section.

Domestic iron ore production and shipments changed less than 1% from 1990, with production increasing slightly and shipments decreasing. Total reported consumption, however, decreased by 16% and consumption of U.S. ores decreased by 12%. The fall in consumption was the result of decreased U.S. steel production, which dropped 11% from that of 1990. World production fell 3% to 900 million metric tons (Mmt).

DOMESTIC DATA COVERAGE

U.S. production data for iron ore are developed by the U.S. Bureau of Mines from two separate, voluntary surveys of domestic operations. The annual "Iron Ore" survey (1066-A) provides the basic data used in this report. Of 46 addressees to whom the 1066-A form was sent, 46 responded, representing 100% of total production shown in tables 1 through 4. In past years, production for nonrespondents to the annual survey was estimated from monthly surveys (1066-M), from railroad reports, or from reported production levels in prior years. This information may be supplemented by employment data, mine inspection reports, and information from consumers.

Data on consumption and stocks of iron ore and agglomerates at iron and steel plants were provided by the American Iron Ore Association (AIOA). AIOA also provided data on ore shipments from loading docks on the upper Great Lakes as well as receipts at transfer docks and furnace yards

nationwide. The dock and steel plant data were compiled jointly by AIOA and the American Iron and Steel Institute (AISI). Data on consumption of iron ore for nonsteel end uses were compiled from information gathered from other Bureau surveys.

BACKGROUND

Industry Structure

History.—The history of iron mining in early America has already been reviewed in several other publications of the U.S. Bureau of Mines and its predecessor.¹ For additional information on the economic history of the entire U.S. iron and steel sector, the reader should refer to the comprehensive works of Father Hogan of Fordham University.²

The history of the iron ore industry as it currently exists began in 1844 with the discovery of "hard" magnetite-hematite ores on the Marquette Range of Michigan and the subsequent founding of the Jackson Mining Co.³ At first, lack of transportation facilities prevented rapid development. However, completion of a shipping canal at Sault Ste. Marie in 1855 opened the way for further development of mining in the Lake Superior region. By 1885, ore had been discovered in the Gogebic and Menominee Ranges of Michigan and Wisconsin, and annual production of ore had climbed to more than 2 Mmt, 20 times the volume in 1860. The high grade of these ores, combined with the low cost of water transportation, made them increasingly

competitive at Eastern furnaces and forced many small mines in New York, Tennessee, and the Mid-Atlantic States to close. This trend was accelerated in the 1880's by production from the Vermilion Range and the discovery of the great Mesabi ore bodies in the 1890's. By the turn of the century, most of the Eastern mines had closed. In Alabama, production of iron ore increased nearly tenfold between 1880 and 1890, and Birmingham was established as a major ironmaking center. During this period, many steel companies acquired iron ore properties in the Lake Superior District, and the production of many smaller mines was consolidated by the formation of large mining companies. The mergers that took place in the steel industry between 1893 and 1905 basically organized the iron ore industry into the structure that exists today.

Hundreds of mines closed during the 1950's because of the depletion of higher grade ores, rapidly rising imports, and costs of underground mining. By 1981, 15 mines accounted for 90% of the Nation's production of iron ore. By 1986, the 15 mines had been reduced to 10 because of increasing imports of steel and 2 deep recessions from which the iron ore and steel industries have not yet fully recovered.

Size and Organization.—In 1991, iron ore was produced by 20 companies operating 24 mines, 16 concentration plants, and 10 pelletizing plants. The mines included 21 open pits and 1 underground operation. Seven mines

operated by four companies accounted for the majority of the output. Virtually all ore was concentrated before shipment, and about 97% was pelletized.

Since the mid-1950's, quasi-symbiotic relationships have existed between several iron ore operations in Canada and the United States because of ownership ties. In 1982, U.S. companies owned about 70% of Canadian production capacity for iron ore and held significant minority interests in iron ore mines in Australia, Brazil, Liberia, and New Zealand. Since then, Japanese interests have acquired part of the Canadian and overseas holdings previously owned by companies in the U.S. iron and steel sector.

The iron ore industry of Canada and the United States has been undergoing a major restructuring since 1985 aimed at lowering pellet costs and improving financial health. The bulk of this restructuring occurred in the summer of 1986, when the industry was experiencing one of its worst years since the Great Depression. Most of the pellet producers had already streamlined their operations by late 1987, when overall demand for steel began to grow. The modest recovery accelerated in 1988, only to level off in 1989.

The breadth and intensity of the restructuring is illustrated by USX Corp., the largest steel producer in the United States. The company was formed after U.S. Steel Corp. acquired the Texas Oil and Gas Corp. USX is now a more diversified company with interests in energy, steel, mineral resources, real estate, and engineering services. Its energy segment includes the Marathon Oil Co. in addition to Texas Oil and Gas Corp. U.S. Steel paid \$6.5 billion for Marathon in 1982. The former U.S. Steel Corp. had been a leader in domestic steelmaking and iron ore mining for about 85 years prior to the 1986 restructuring.

USX owns and operates the Minntac Mine at Mountain Iron, MN. Minntac is the largest iron mine in the United States and supplies fluxed pellets to USX's blast furnaces at Gary, IN, and Dravosburg, PA. At the end of 1988, USX and the Blackstone Group formed a joint venture

known as Transtar Inc., which manages a variety of bulk transportation subsidiaries. USX sold 56% of its extensive transportation holdings to Transtar for about \$600 million. A number of USX railroad lines were involved, including the Duluth, Missabe, and Iron Range Railway Co. (DM&IR). The new transportation company also acquired USX's lake shipping and river barging operations. In 1989, USX sold its 100% equity in the Quebec Cartier Mining Co. (QCM) to Dofasco Inc.

The giant Canadian iron ore operation is currently owned by Dofasco (50% equity), Mitsui & Co. Ltd. of Japan (25%), and Companhia Auxiliadora de Empresas de Mineracao (CAEMI) of Brazil (25%).

At the beginning of 1991, USX announced plans to divide its common stock into separate steel and energy issues. The company's U.S. Diversified Group (real estate, engineering services, timber, and certain coal interests) was to be included with the steel group. Stockholders approved the stock restructuring proposal at their annual meeting on May 6, 1991. Approval of the May stock proposal facilitates further restructuring of the corporation and requires the steel group to fund capital expenditures from its own internally generated cash-flow. It is not known at this time what effect the stock separation and accompanying corporate changes will have on the Minntac operation.

Recent technological advances have affected not only day-to-day operations, but also the structure of the industry. An increasing number of integrated steelworks in North America are using fluxed pellets. This newer, more easily reducible type of pellet is created by adding limestone (CaCO_3) and/or dolomite [$(\text{Ca},\text{Mg})\text{CO}_3$] to the iron ore concentrate during the balling stage. Sufficient fluxstone is added to raise the ratio of $(\text{CaO} + \text{MgO})/(\text{SiO}_2 + \text{Al}_2\text{O}_3)$ in the pellet to above 0.6. The most common ratio is about 1. Fluxed pellets comprised 39% of total U.S. production in 1990. Idle capacity was brought on-stream at three mining complexes on the Mesabi Range during 1989 to meet

increased pellet demand. The idled complex of Reserve Mining Co. at Silver Bay, MN, was renovated by Cyprus during the last quarter of 1989. Cyprus shipped a trial batch of fluxed pellets in April 1990.

Combined United States and Canadian production represented only about 11% of the world output of usable ore in 1989. At least 45 other countries mined crude ore during the year. The leading producer was the U.S.S.R., which accounted for about 25% of world output in terms of metal content, followed by Brazil with 19% and Australia with 12%. Trends in world mine production since 1986 are shown on a country basis in table 22. Major mines are listed individually in table 21.

In 1989, the U.S.S.R. produced 241.0 Mmt of direct-shipping ore and concentrate. A large part of the concentrate was consumed to make 68.7 Mmt of pellets. The bulk of the iron ore produced in Australia, Brazil, India, and the Republic of South Africa consisted of high-grade direct-shipping ore or products derived from much higher grade crude ores than those mined in the United States.

Geology-Resources

Iron is the fourth most abundant rock-forming element, comprising about 5% of the Earth's crust. Astrophysical and seismic evidence suggest that the element has also combined with nickel to make up the bulk of the Earth's core. A small part of the crustal iron has been concentrated by sedimentary, igneous, or metamorphic processes into deposits containing up to 70% of the element.

The largest concentrations of iron are found in banded sedimentary iron formations of Precambrian age. These formations currently supply most of the world's iron ore and constitute the bulk of the world's iron resources. Precambrian ores are mined extensively in Africa, Australia, Canada, China, India, South America, the United States, and the U.S.S.R. Individual banded iron formations (BIF's) can vary from less than 30 to 600 meters (m) in thickness.

Some are relatively flat-lying, while others are steeply dipping or have been complexly folded. Some BIF's are exposed almost continuously along the margins of geosynclines and commonly underlie basin areas of hundreds or thousands of square kilometers (km²). Most consist of fine-grained iron oxides and quartz, with accessory iron silicates and in some places iron-bearing carbonates, and contain 20% to 40% iron. These rocks comprise ores of the taconite type mined in Canada, China, Norway, the United States, and the U.S.S.R.

Locally, the BIF's have been concentrated by natural processes to form high-grade deposits of hematite or goethite by leaching of silica and oxidation of ferrous minerals. The high-grade ores are classed as residual or replacement deposits, depending on whether removal of silica was accompanied by introduction of additional iron oxide. The residual ores are usually earthy, porous, and contain 50% to 60% iron in their natural state. Examples are the soft ores of the Lake Superior District, the Schefferville District of Labrador, and the Krivoy Rog District of the Ukrainian S.S.R. Some soft ores appear to be merely decomposed bodies of BIF, containing 20% to 40% iron in the form of martite, hematite, or goethite. Examples of the latter are bodies of "wash ore" in the western Mesabi Range, which are highly siliceous but easily concentrated by gravity methods.

Replacement ores in the Precambrian BIF's are usually dense, massive, and contain 64% to 68% iron. Often, the ores retain banded structures of the original sedimentary rock. Examples are the hard ores of the Vermilion Range, MN; Steep Rock and Michipicoten Districts of Ontario; Minas Gerais, Brazil; Fort Gouraud, Mauritania; and Sishen, Republic of South Africa.

Another class of sedimentary iron deposits, of regional importance in the southeastern United States and Western Europe, is oolitic ironstone of Paleozoic to Cretaceous age. The formations are extensive laterally and contain 20% to 40% iron, but they differ from the

Precambrian BIF's in several important respects. They are usually less than 15 m thick, and minable layers are commonly less than 6 m thick. The deposits rarely contain more than 48% iron, and most contain only 25% to 35% iron. The ore consists of very fine-grained hematite, quartz, chamosite,⁴ and siderite in varying proportions; sometimes enough calcite is present to make self-fluxing ore. The ore is usually high in phosphorus and difficult to beneficiate. Oolitic ironstones were mined until recently in Alabama, Newfoundland, and the United Kingdom and are still mined extensively in France and to a lesser extent in central Europe. They are also mined in Egypt and comprise most of the iron resources of Pakistan.

A third type of sedimentary ore, consisting of siderite or limonite in flat-lying lenses up to 6 m thick, is mined in east Texas from the Weches Formation of Eocene age. The ore is associated with glauconitic sand and clay and contains up to 35% iron.

Massive deposits of magnetite, sometimes with hematite, thought to be of igneous origin, are important sources of iron ore in many parts of the world. These deposits can contain as much as 65% iron and are often rich in titanium and vanadium, as at Lake Sanford, NY. There are two principal types of these igneous deposits: magmatic segregations and pyrometamorphic replacements. The first type is represented by irregular or layered masses that appear to have formed by segregation of magnetite crystals in magma, or as tabular, sheetlike bodies formed by injection of an iron-rich fluid into surrounding rocks. The Precambrian Bushveld Igneous Complex of the Republic of South Africa with its layers of magnetite and chromite is frequently cited as an example of magmatic segregation and crystal settling. The sill-like ore bodies at Kiruna, Sweden, and Pea Ridge, MO, represent the injection version of the process. The magnetite ores in these last two deposits contain significant amounts of fluorapatite, which must be removed during beneficiation.

Pyrometamorphic deposits are concentrations of magnetite that have replaced portions of the limestone or igneous country rock at or near the contact of an igneous intrusion. These deposits may be partly altered to hematite and contain up to 65% iron, depending on the extent of replacement. Garnet, epidote, and wollastonite are commonly formed along with the magnetite during the thermal metamorphism of the country rock. Deposits of this type are commonly associated with Jurassic or younger intrusives in the Western United States, Mexico, and western South America; they are also found in Pennsylvania. Examples include Iron Springs, UT; Eagle Mountain, CA; Hanover, NM; Cornwall and Morgantown, PA; El Romeral, Chile; and Marcona, Peru.

Technology

A study entitled "An Updated Analysis of Mortality in a Cohort of Minnesota Taconite Miners and Millers" was published. The report, sponsored by the AIOA, is the second update of a study of 3,444 taconite miners and mill operators who were first exposed to taconite in the period 1947-58. Previous analyses of deaths through 1977 and again through 1983 showed no significant excess deaths from any specific causes. The first study, initiated in 1979, was performed because of reports in the early 1970's that some taconite ore contained amphibole minerals that had characteristics similar but not identical to those of asbestos, which could be a health hazard. In addition, this study examined the potential for adverse health effects from exposure to crystalline silica, a constituent of the host rock and ore. The updated study extended the observation period for an additional 5 years, through 1988, which means that from 30 to 41 years elapsed from the workers' first exposure. This was an important step because of the long latency periods between exposure and disease that are characteristic of asbestos and crystalline silica-related diseases. The results of the study supported the conclusions of the two earlier studies that

there is no evidence of asbestos-related disease associated with the mining and milling of taconite in northeastern Minnesota. Also, there is no evidence that silica in the taconite ore bodies increased the risk of silicosis or lung cancer.

Column flotation in recent years gained acceptance by the mineral industry because of the advantages it offers over that of conventional flotation equipment such as its capability of producing a higher grade concentrate. Other benefits include lower capital and operating costs and improved control and stability. In the iron ore industry columns have been found to be effective in treating fine-grained concentrates in the final stages of cleaning.⁵ Columns provide greater selectivity than conventional equipment in removing silica and iron middlings. Iron middlings are grains that contain both iron and silica.

Economic Factors

The United States has exhausted the reserves of high-grade direct-shipping ore it once had in Michigan and Minnesota. Almost all of the ore being mined now is low-grade taconite, which requires costly beneficiation and pelletizing. Moreover, the taconite mining and pelletizing complexes are deep in the interior of the country, far from any saltwater harbor. Because of the advantages of Great Lakes shipping, U.S. pellets are currently competitive at Gary, Cleveland, and Detroit. However, high rail costs put U.S. pellets at a disadvantage in the Mid-Atlantic States and Alabama. Imported ores and agglomerates from Brazil, Canada, and Venezuela constitute the bulk of the iron units consumed at these coastal steelworks.

The St. Lawrence Seaway is a mixed blessing for the mining industry, being a bottleneck for ore carriers as well as an inexpensive means of transport in the Great Lakes region. The eight locks in the Welland Canal and the seven locks in the St. Lawrence River are all similar in size and have a gate-to-gate length of 262 m. The relatively short length of each lock prevents oceangoing ore carriers

longer than 222 m from entering the Great Lakes. At the same time, domestic 1,000 footers cannot leave the Lakes. Foreign ore bound for Indiana or Ohio either has to be offloaded onto smaller vessels in the gulf of the St. Lawrence or transferred to rail cars at Baltimore or Philadelphia. In some cases, ore is barged from the Port of New Orleans up the Mississippi River to steelworks in the Ohio River Valley and western Pennsylvania. The high rail costs that keep domestic ores from going to the coastal steelworks also keep foreign ores out of the inland steelmaking regions.

Operating Factors

Employment.—Statistics on employment and productivity in the U.S. iron ore industry in 1991, shown in table 2, were derived from quarterly employment data supplied by the Mine Safety and Health Administration (MSHA) and from production data derived from U.S. Bureau of Mines surveys. Both sets of data were obtained from producers' reports.

The statistics include production workers employed at mines, concentrators, pelletizing plants, and in repair and maintenance shops, but do not include 830 persons engaged in management, research, or officework at mines and plants. Employees engaged in ore preparation, such as sintering, at blast furnace sites are not included.

Because employment data reported to MSHA are primarily for safety analysis, hours spent by salaried employees in mines or plants may be included by operators in the total number of hours worked at individual mines or plants. This has resulted in understatement of calculated productivity by 10% to 25% for some operations, but its effect on others is not known. If company reporting practice is consistent, however, comparison of productivity from one year to the next should be reasonably valid. Average quarterly employment was 2.9% higher than that of 1990.

Transportation.—Transportation of iron ore on the U.S. Great Lakes has changed considerably since 1971, when the first self-unloading "super-carrier," capable of carrying 45,000 metric tons (mt) of iron ore, was placed in service. Since then, 12 similar vessels have been built, each about 300 m (1,000 feet) long and capable of carrying about 60,000 mt of iron ore pellets. Each of these carriers replaced about four older vessels and can deliver about 2.5 Mmt of ore to lower lake ports during an 8-month shipping season. The last of this group of ships was completed in 1981.⁶ While these vessels were being built, a similar number of older ships were lengthened to increase their carrying capacity and were also fitted with self-unloading equipment. By the spring of 1991, all but 2 of the 58 bulk carriers in the U.S.-flag fleet were self-unloaders. The average cargo capacity of the lake vessels has thus increased since 1971, while the total number of vessels has been reduced by more than 60%.

To accommodate the "1,000 footers," new loading facilities and materials handling systems were built at four of the seven upper lake ports, the last of which was completed in 1983, and three new receiving terminals were completed on Lake Erie. The self-unloading vessels have all but eliminated the use of Hulett clamshell unloaders at lower lake ports. The "1,000 footers" have unloading capacities of up to 10,000 metric tons per hour (mt/hr), while loading capacities at upper lake ports are of similar capacity. Details on individual port facilities are given in Greenwood's Guide to Great Lakes Shipping.⁷

Cargo capacities of vessels traveling the St. Lawrence Seaway between Montreal and Lake Erie are still limited to about 26,000 mt. On the north shore of Lake Erie, Stelco Inc., which has equity in several U.S. taconite mines, completed an unloading facility in 1979 that can accommodate 1,000-foot carriers. The Nanticoke facility can handle up to 6,000 mt of pellets per hour and has a stockpiling capacity of 860,000 mt of pellets and 1.06 Mmt of coal.⁸

U.S. coastal ports are still limited to incoming cargoes of 65,000 mt or less. Hunterston, Rotterdam, Taranto, and several other ports in Western Europe can now accommodate iron ore cargoes of 150,000 to 300,000 mt. The Ertsoverslagbedrijf Europoort terminal west of Rotterdam currently holds the world record for the largest single cargo of iron ore ever unloaded. On August 22, 1989, 356,541 mt of Carajas sinter feed and natural pellet ore was delivered to the terminal by the world's largest ore carrier, the 365,000-deadweight-ton (dwt) *Berge Stahl*. The *Berge Stahl* and the *Docefford*, another vessel capable of carrying more than 300,000 mt of ore, were built in 1986, primarily for trade between Brazil and Japan. In Japan, cargoes of 200,000 to 260,000 mt can be accommodated at Fukuyama, Kakogawa, Keihin, and Oita. Similar size cargoes are also routinely delivered to the island of Mindanao in the Philippines for sintering. The 351-m-long main berth of the Philippine Sinter Corp. has a depth of 23 m and can handle all but the very largest vessels that load at Ponta da Madeira. The three major loading ports in Western Australia (Dampier, Port Hedland, and Port Walcott) have all been modernized and had their berths deepened to permit loading of ore carriers of the 250,000-dwt class.

Two major pipelines for transport of iron ore slurries were completed in northern Mexico in 1983, connecting the La Perla and Hercules Mines with a pelletizing plant in Monclova. An 8-inch, 87-km line from La Perla is connected to a 14-inch, 295-km line that runs from the Hercules Mine to Monclova. The pipeline system can transport up to 4.5 Mmt of iron ore concentrates per year. A second system is operating in the Pacific Cordillera of Mexico. Two parallel lines transport concentrates 45 km from the Pena Colorada Mine in the mountains of northwestern Colima down to a pelletizing plant on the coast near Manzanillo. The 900-m drop in elevation permits the lines to be gravity operated. Major pipelines have also been built in Brazil and India since 1977, and others

are operating in Argentina, Australia, New Zealand, and Peru.

ANNUAL REVIEW

Production

Domestic iron ore production showed a modest increase in 1991, rising from 56.4 Mmt in 1990 to 56.7 Mmt. The iron ore industry increased its output of usable ore by 0.6%. Productivity for usable ore in the Lake Superior District was unchanged from that of 1990.

Iron ore was produced by 21 open pit mines and 1 underground mine. Twenty-two mines produced ore for the iron and steel industry, while the remainder shipped ore mainly to cement plants. Installed domestic production capacity for usable ore on December 31, 1991, was estimated at 83 million metric tons per year (Mmt/yr), of which 81 Mmt was pellets. Total output of usable ore was equivalent to about 70% of installed production capacity, up from 68% in 1990. An average of 3.2 mt of crude ore was mined in 1991 for each mt of usable ore produced. This ratio does not take into account the tonnage of waste rock or overburden removed. The ratio of total materials mined to usable ore produced was probably greater than 5:1. Low-grade ores of the taconite type mined in Michigan and Minnesota accounted for 99% of total crude ore production. U.S. production of pellets totaled 54.78 Mmt, 97% of usable ore output. The average iron content of usable ore produced was 62.6%. Shipments from U.S. loading docks on the upper Great Lakes totaled 51.10 Mmt in 1991.

Michigan.—Michigan accounted for 22% of the national output of usable ore in 1991. Ninety-nine percent of the State's production consisted of pellets produced at the Empire and Tilden Mines near Ishpeming in Marquette County. Both mining ventures are managed by Cleveland Cliffs Inc.'s (CCI) Cleveland-Cliffs Iron subsidiary. Empire shipped 7.5 Mmt of pellets produced from magnetite concentrate. Tilden shipped

3.8 Mmt of magnetite pellets and 1.2 Mmt of hematite pellets, for a total of 5.0 Mmt.

Production of usable ore was up 34% from the 1990 figure of 9.5 Mmt. Production of pellets totaled 12.6 Mmt, of which 7.8 Mmt was made at the Empire plant and 4.8 Mmt was made at Tilden.

On March 19, the Marquette Range produced its 300 millionth long ton of iron ore pellets. Five mines contributed to the overall total since pellets were first produced in 1956.

Minnesota.—Minnesota produced 76% of the national output of usable ore in 1991. All of the State's production came from open pit mines on the Mesabi Range. Production of pellets totaled 42.2 Mmt, equivalent to about 87% of installed production capacity of the State's seven taconite plants.

In mid-August, CCI restructured its Pickands-Mather subsidiary. Pickands Mather was renamed the Cliffs Mining Co., but the total number of employees in the organization was unchanged. The restructuring was part of an ongoing integration process begun in 1986 when CCI acquired all of the outstanding stock in Pickands Mather & Co. from Moore McCormack Resources. At the time of the acquisition, Pickands Mather was managing four large iron ore properties: the Hoyt Lakes complex, the neighboring Hibbing Taconite Co., Wabush Mines of Quebec, and Savage River Mines of Tasmania.

The restructured subsidiary was to retain its ownership interests in both the Hibbing Taconite joint venture and Wabush Mines. It would also continue to manage both Hibbing and Wabush, as well as the LTV Steel Mining Co. The Cleveland-Cliffs Iron Co., CCI's other principal subsidiary, will continue to hold ownership interests in the Empire and Tilden Mines of Michigan and manage both operations. All of CCI's salaried personnel in the Lake Superior District who have been providing central services to the mines are now part of another newly formed subsidiary, Cliffs Mining Services Co.

On August 1, 1991, Eveleth Mines launched a \$7.5 million project to expand crushing capacity at its taconite operations on the Mesabi Range. The taconite came from two pits, which straddle the western edge of the City of Eveleth. Each of the pits had its own crushing plant and could be operated independently. After crushing, the ore was railed 14 km south to the company's 6.2 Mmt/yr pelletizing plant near Forbes. Most of the project money was used to upgrade the existing crusher building at the Thunderbird North Mine and replace the primary crusher. The crusher dump bays were enlarged, and a third secondary crusher was added to the middle level of the building. The modifications were to increase the output of the crusher from 38,000 mt to 60,000 mt of crude taconite per day. The 60% increase in capacity was to allow Eveleth to begin developing new reserves near the old Auburn Mine northwest of Midway. At the same time, the company would be able to idle operations at its Thunderbird South Mine. According to company officials, the South Mine had only about 1 year of stripped ore left and was more costly to mine because of its higher stripping ratio.

On September 6, LTV Steel Co. halted mining at its McKinley Extension Mine near Aurora. The McKinley Extension was the last active natural ore mine not only on the Mesabi Range, but in the entire Lake Superior District. The closure brought an end to an era in Minnesota mining, which began in 1884 when the Minnesota Iron Co. began shipping natural ore from its Soudan underground mine near Lake Vermilion. Natural ores were the mainstay of the U.S. iron ore industry prior to the development of the taconite pelletizing process. The old Lake Superior ores averaged 50% to 60% Fe and could be shipped directly to the steelworks without prior beneficiation. In 1944, at the peak of World War II, 103 natural ore mines were operating in Minnesota and another 43 in Michigan. That year, the two States shipped 65.5 Mmt of crude ore directly to consumers and another 23.9 Mmt to beneficiation plants. The ore was

essentially all hematite and averaged 51.9% Fe. By the end of the Vietnam Conflict, most of the natural ore had been mined out. The McKinley Extension Mine is in White Township, about 8 km southwest of LTV's Hoyt Lakes pelletizing plant. The Northwest Ore Div. of LTV has been operating the mine under a lease from the USS Minnesota Ore Operations of USX Corp. since 1983. The lease was obtained from the United States Steel Corp. by Jones & Laughlin Steel Corp., one of LTV's predecessors. The mine consists of two pits: the Donora and the Stephens. LTV was forced to halt operations after exhausting the remaining pockets of ore in the Donora. The last 15,000 mt of ore in the Stephens pit was removed in 1990. LTV was considering reactivating the Connie Mine near Virginia, MN, to meet part of the demand for natural ore. The Connie Mine is in Wuori Township, on the western edge of the Minorca taconite operations of Inland Steel Mining Co.

CCI became the principal supplier of pellets to the Weirton Steel Corp. of West Virginia. Under an agreement concluded on October 2, pellet shipments were to begin in 1992 and run for 12 years. The Cleveland-based iron ore merchant expected to supply Weirton with at least 1.0 Mmt of pellets annually. As part of a parallel agreement, CCI invested \$25 million in a special nonmarketable issue of Weirton preferred stock. The preferred stock pays a cash dividend of 12.5% per year, payable quarterly. Weirton had four blast furnaces, with working volumes ranging from 1,300 to 1,530 cubic meters.

In 1990, Inland Steel Mining Co. began construction of its new Laurentian Taconite Mine, the first new mine to be constructed on the Mesabi Range in Minnesota in more than a decade. Inland Steel Mining is a wholly owned subsidiary of the Inland Steel Co. The new open pit operation will provide iron units for the parent company's integrated steelworks at Indiana Harbor, IN. The mine entered service in 1991, when crude taconite from the first benches was being trucked 10 km to Inland's existing Minorca mining and pelletizing complex

on the northeastern edge of Virginia, MN. The Laurentian taconite was replacing ore from the Minorca pit, where reserves are almost exhausted. The new mine was to enable the 2.5-Mmt/yr pelletizing plant to continue operating until the year 2031. The initial stage of the project cost more than \$10 million. Inland expected to spend at least another \$10 million to fully develop the Laurentian Mine site.

The Laurentian ore body provides the plant with more than 15 years of reserves. Inland also hoped to negotiate leases on adjoining properties that could supply another 25 years of reserves. Inland has additional ore at two other sites—the Ordean Reserve west of Minorca and the East Rouchleau pit on the outskirts of Virginia.

In June 1991, Inland began blending the Laurentian ore with ore from Minorca. The blending may be able to extend the life of the Minorca pit until 1994, when mining would be shifted entirely to the new ore body. A dedicated haul road was constructed from the pelletizing plant through the Pike River Basin to the mine site. The use of a conveyor system in place of the haul road was not considered economically feasible.

Missouri.—The Pea Ridge Iron Ore Co. produced iron oxide powder at its mining complex near Sullivan, MO. The company has the only active underground iron mine in the country. The mine is on the northeast flank of the Ozark uplift and has proven reserves of 160 Mmt of ore grading 55% magnetic iron. The mining and pelletizing complex was developed jointly by St. Joe Minerals Corp. and Bethlehem Steel Corp. between 1957 and 1964 at a cost of about \$52 million. At that time, Pea Ridge was known as the Meramec Mining Co.

In December 1990, Pea Ridge's contract with National Steel expired, leaving Pea Ridge without a blast furnace customer. In January 1991, the company ceased pellet production and began concentrating on specialty iron oxide products, which had formerly been coproducts.

Utah.—Geneva Steel of Utah operated two open pit mines in the Pinto District of Iron County. Reserves were depleted at the Excelsior Mine during the year, leaving the Comstock and Mountain Lion as the only operational mines. The district, 32 km west of Cedar City, has provided magnetite and hematite ores for blast furnaces in the Rocky Mountain region on an intermittent basis since 1923. Coarse ore and fines were shipped 370 km on the Union Pacific Railroad to Geneva's integrated steelworks at Provo. The ore was hauled twice a week in train units of 72 cars, each with a capacity of 100 short tons. The actual mining was contracted out to the Gilbert Development Corp.

Other States.—Three California mines produced iron ore during the year—the Baxter, the Beck, and the Soledad Canyon. The bulk of the shipments went to cement plants in the Los Angeles basin. The Baxter and Beck Mines are both in San Bernardino County in the eastern half of the Mohave Desert. The Baxter Mine is operated by the California Portland Cement Co.; the Beck Mine, by Standard Industrial Minerals Inc. The P.W. Gillibrand Co. produced a magnetite concentrate as a byproduct of its Soledad Canyon sand and gravel operations in Los Angeles County. The Soledad Canyon District is at the northwestern end of the San Gabriel Mountains and encompasses parts of the environmentally sensitive Angeles National Forest. The district has several promising alluvial and lode deposits of titaniferous magnetite and ilmenite.

In South Dakota, Pete Lien & Sons Inc. mined low-grade hematite at the CF&I pit near Nemo in Lawrence County. The mine was reopened in 1988 after a hiatus of 9 years, but operated only during part of 1991. The company produced ore averaging 29.1% Fe. Production was limited by the relative remoteness of the Black Hills mine site from consumers. The bulk of the ore was shipped to the Dakota cement plant operated at Rapid City by the State Cement Commission. The ore comes

from a 30- to 90-m-thick Precambrian iron formation that forms a ridge along the east side of Boxelder Valley.

Consumption and Uses

The U.S. steel industry accounts for 98% of domestic iron ore consumption. The steel industry experienced a poor year as production and shipments of steel products declined along with the recessionary economy. Production of raw steel in the United States fell more than 11%.

Another factor affecting the consumption of iron ore is that electric arc furnaces, used in steelmaking primarily by minimills, do not use iron ore. Electric arc furnace steelmaking accounted for 38.4% of total steelmaking in 1991. This was the largest share for electric arc furnace steelmaking in the United States.

Consumption of iron ore was 13.7% lower than the figure for 1990. Consumption for ironmaking and steelmaking totaled 63.662 Mmt. Monthly consumption of pellets, direct-shipment ore, and merchant sinter by the industry averaged 5.31 Mmt compared with 6.14 Mmt in 1990. Reported consumption of iron ore for manufacture of cement, heavy-medium materials, animal feed, ballast, ferrites, pigments, and other nonsteel products was 691,000 mt.

At the end of 1991, the U.S. economy was struggling to overcome recessionary problems. U.S. production of hot metal and pig iron totaled 64.9 Mmt, an 11% drop from that of 1990. During 1991, the number of blast furnaces in operation ranged from 40 to 45.

Consumption of iron ore and all types of agglomerates reported to the AISI by integrated producers of iron and steel totaled 63.59 Mmt. This included 51.33 Mmt of pellets; 10.30 Mmt of sinter, briquettes, etc.; and 1.95 Mmt of natural coarse ore. Of the primary ore consumed, 76% was of domestic origin, 11% came from Canada, and 12% came from other countries. Other materials consumed in sintering plants included mill scale, flue dust, limestone and dolomite,

slag and slag scrap, and coke breeze. Other iron-bearing materials charged to blast furnaces included steel-furnace slag, mill scale, and slag scrap. According to AISI, 2.54 Mmt of ferrous scrap was consumed in blast furnaces in 1991.

In January, LTV Corp. idled one of two operable blast furnaces at its Cleveland Works in Ohio. Then, in February, Inland Steel Co. mothballed its "B" blast furnace at Plant No. 3 in East Chicago, IN. Plant No. 3's "A" furnace has been shut down since July 1990. The bulk of Inland's production will continue to come from the giant No. 7 furnace, which currently produces about 8,700 mt of metal per day at Plant No. 2. Inland does not plan to restart Plant No. 3 until 1994 when No. 7 will have to be shut down for relining.

Both Bethlehem Steel Corp. and USX Corp. have made plans to close some of their older hot-metal operations on the East Coast. The Bethlehem closures were linked to a proposed joint venture with British Steel PLC. Under the plan, obsolete ironmaking and steelmaking operations at Bethlehem, PA, would be permanently closed.

In February, USX Corp. announced plans to halt ironmaking and steelmaking at its Fairless Hills works near Philadelphia. The works had two operable blast furnaces. The shutdown of the hot-metal part of the Fairless operations would allow the USS steelmaking division to reach its 100% continuous casting goal by late 1992. In 1990, Fairless operated three of eight open-hearth furnaces built in the early 1950's.

Stocks

Stocks of iron ore and agglomerates reported at U.S. mines, docks, and consuming plants have been gradually dropping for more than 30 years. This trend temporarily reversed itself in 1988, but has since continued downward. At yearend, total industry stocks were 24.0 Mmt. Furnace yard stocks stood at 17.6 Mmt and included 12.7 Mmt of domestic ores, 2.5 Mmt of Canadian ores, and 2.4 Mmt of foreign ores. Mine stocks at

yearend were 11.3% higher than those of 1990.

Stocks of unagglomerated concentrates reported at pelletizing plants totaled 1.8 Mmt at yearend, an increase of 100% from that of 1990, and ranged in Fe content from 47% to 68%. This material is not included in mine stocks of usable ore reported in the accompanying tables because it is considered an intermediate product. Stocks of byproduct ore also have been excluded since 1983 from the mine stock data to avoid disclosing company proprietary information.

Transportation

In 1991, seaborne iron ore trade was the greatest generator of dry bulk shipping demand in the world. About 375 Mmt was shipped more than 1.96 trillion ton-miles.

Great Lakes shipping continued to play a key role in the competitiveness of the U.S. iron ore industry. Relatively mild weather allowed the Corps of Engineers to keep the Soo locks open until January 15, 1991. Ore shipments from Escanaba on Lake Michigan continued until January 31. The 1990-91 navigation season lasted 335 days (March 3 to February 1) and was the longest in more than a decade. The U.S. Great Lakes fleet hauled 49.9 Mmt of ore, agglomerates, and related products during the 1990-91 season.

The fleet operated 57 of its 65 serviceable vessels, with the 57 vessels accounting for 93% of carrying capacity. Since 1980, the number of U.S.-flag vessels on the Great Lakes has dropped from about 140 to 65. At the same time, the average carrying capacity has risen from 20,900 mt to 26,000 mt. Of the 65 vessels, 6 were cement carriers and 3 were self-propelled tankers.

Prices

Foreign iron ore producers won price hikes in Japan and Western Europe for the third consecutive year. In Japan, prices for lump ore were up about 6%; fines, about 8%. Very few published prices for domestically produced pellets changed in 1991. Oglebay Norton was

still quoting a price of 72.45 cents per long ton unit of iron, natural, for its standard grades of Lake Superior pellets. A long ton unit (ltu) is equivalent to 0.01 long ton or 22.4 pounds. The quotation included delivery to rail-of-vessel at lower lake ports. The Pickands Mather quotation of 59.40 for pellets was still in effect at the end of 1991. The price for Minntac acid pellets was left at 37.344 cents per dry ltu of iron, delivered into railcars at the Minnesota mine.

Published f.o.b. prices for direct-reduced iron (DRI) were also unchanged from those quoted in 1990 and were as follows, per mt: at Georgetown, SC, \$125.00 to \$135.00; at Contrecoeur, Quebec, \$115.00; and at Point Lisas, Trinidad and Tobago, \$120.00.

Price negotiations opened in Europe in December 1990, but quickly bogged down. Brazil's Cia. Vale do Rio Doce (CVRD) asked for increases on the order of 18% so that it could (1) begin upgrading its older operations in the Iron Quadrangle, and (2) continue to properly service the enormous debt incurred in developing the giant Carajas Mine. At the end of January, Rohstoffhandel GmbH and Erzkontor Ruhr GmbH, the principal buyers for the German steel industry, finally agreed to price increases of 7.95% for Itabira fines and 6.95% for Carajas fines. In the settlements that followed, CVRD's competitors obtained increases that ranged from 0.56% for Hamersley lump to 8.89% for Carol Lake concentrates. The suppliers' positions were supported by three arguments. First, producers in Western Australia may have to develop several new mines to meet the growing demand for iron ore in the Far East. This would require a heavy financial investment on the producers' part. Second, iron ore shipments from Liberia were completely disrupted by the recent civil war and ensuing political uncertainty. Last, Canadian producers closed two pelletizing operations in Ontario and were temporarily cutting back production in the Quebec-Labrador Trough.

Foreign Trade

U.S. exports of iron ore were 27% higher than those of 1990. Virtually all exports consisted of pellets and concentrates shipped via the Great Lakes to Canadian steel companies that are partners in U.S. taconite projects in Michigan and Minnesota. U.S. imports of iron ore dropped 26% to 13.3 Mmt.

Net imports for 1991 were one-third lower than the average of the previous 4 years and were equivalent to 22% of U.S. ore consumption. Canada's share of net imports was 79%; Brazil's was 29%.

World Review

At least 48 countries mined iron ore during the year, producing a total of 901 Mmt. The U.S.S.R. was the largest producer, with an output of 200 Mmt of concentrate or direct-shipping ore plus 68 Mmt of pellets. Soviet production accounted for about 21% of the world's marketable output in terms of metal content. World production of pig iron, which directly reflects ore consumption, decreased by 4.5% to 509 Mmt. World DRI production rose by 7.6% to 19,755 mt.

For the first time since 1984, Australia surpassed Brazil as the leading exporter of iron ore, shipping 116 Mmt to world markets, considerably more than that in 1990. Australia's top customer, Japan, accounted for more than one-half of its exports. Brazil's primary customers were the European Community (EC) and Japan.

World production of pellets was estimated at 213.2 Mmt, about 84% of rated capacity.

Integrated iron ore operations have become extremely complex and resemble medium-sized towns in some cases. The production capacity of an operation of this magnitude is determined by equipment limitations at several stages of recovery. To simplify analysis and make comparisons of individual mines easier, data were collected that represent the rated or design capacity at three key points in the recovery process: crusher-screen output, concentrator output, and

pelletizing furnace output. These three points were chosen because they serve to readily separate the mining, beneficiating, and agglomerating stages of the operation. At the first two points, the iron ore is already in a marketable form and can be diverted for sale or tolling if bottlenecks occur either downstream at the operation or upstream at competitors' facilities.

Changes in the economics of the process could also make diversion feasible. Table 24 shows world pelletizing capability at the close of 1991. The data represent the rated capacities of 82 plants in 26 countries. A significant part of the data was collected by the International Iron and Steel Institute in 1987. The table excludes plants that have not produced since 1982. Four of these idled plants are identified in the table footnotes because they could be reactivated in some realistic scenarios. Table 24 also excludes sintering plants.

Australia.—In 1991, the three major producers, BHP Iron Ore Ltd., Hamersley Iron Pty. Ltd., and Robe River Iron Associates, were implementing long-term expansion plans, primarily infrastructure improvements.

BHP Iron Ore Ltd. made a series of moves aimed at making the company a larger producer, perhaps surpassing Hamersley as the country's largest producer. BHP's primary mine, Mount Whaleback, was made more productive by widening the pit floor, thereby facilitating equipment movement. It was expected that production at the mine would reach 26 to 28 Mmt/yr in the near future. Railway and mine construction work at BHP's Yandi deposit, 90 km west of Newman, proceeded well. The Yandi (previously known as the Yandicoogina) was expected to begin production early in 1992 at 5 Mmt/yr. The mine design, however, was based on a yearly capacity of more than 7 Mmt and could be expanded to 10 Mmt/yr with minimum capital costs, as most of the infrastructure would already be in place. In 1990, BHP, already part owner of Mount Goldsworthy Mining Associates, purchased the balance. Subsequently,

BHP sold 15% of the operation to its Japanese partners, CI Minerals and Mitsui C. Itoh Iron Ore Corp. In 1991, the company began replacing the mine's 120-mt truck fleet with 200-mt trucks. Production at the mine, which was 7 Mmt/yr, was expected to increase to 8.5 Mmt/yr. The 1991 combined capacity at ore bodies No. 25 and No. 29, adjacent to Yandi, was more than 5 Mmt/yr, and the concentrator at Whaleback was capable of producing 3 Mmt/yr from stockpiled low-grade ore. Korean steelmaker, Pohang Iron & Steel (Posco), became BHP's largest single customer following contract negotiations in 1991. Much of the ore resulting from BHP's expansions was expected to go to Posco. BHP shipped 54,811 Mmt of ore during the year.

Hamersley Iron Pty. Ltd., the largest Australian iron ore producer, became the first Australian iron ore producer to produce and ship more than 50 million long tons in 1 year. Production increased from 43.9 Mmt in 1990 to 50.2, while shipments for the same period rose from 40.9 to 50.6 Mmt. The commissioning of a new haul truck fleet at the Mount Tom Price Mine helped increase productivity to record levels. At the Paraburdoo Mine, upgrading of the processing plant resulted in increased throughput and record production. Production of ore from the Channar Mine increased during the year while development work continued with the opening of new mining areas. Development of the Marandoo project was significantly delayed during the year. The Marandoo deposit, which was reported to contain 400 Mmt of high-grade ore, was slated to come on-stream in mid-1994. Located 40 km east of the Mount Tom Price Mine, the Marandoo deposit is near the surface and varies in thickness from 27 to 40 m. The Mount Tom Price Mine was considered the jewel in the company's operation as it supplied high-quality ore, of which 55% was lump and the remainder fines. However, reserves at Tom Price were being depleted, and to maintain a highly marketable product mix, Hamersley needed to supplement the output of Tom

Price with Marandoo ore. As Australia's largest iron ore producer, Hamersley produced about 50 Mmt/yr. Because Marandoo would extend the life of the Tom Price by 4 years by adding 10 Mmt/yr of production, its development was considered essential to Hamersley's future. Development was delayed by claims by an Aboriginal community, who rejected anthropological and archeological studies stating that there were no significant Aboriginal sites in the Marandoo region. The Aboriginal community claimed to have two significant sites there and was concerned about them being disturbed by the introduction of mining and the resulting infrastructure. The Western Australian government decided to conduct another anthropological study. The issue was unresolved at yearend.

In 1991, Robe River was the world's fastest growing major iron ore producer, the result of a long-term expansion program. Under the program, the company was making considerable improvements in the five following areas: (1) in the area of mining, the company purchased larger capacity trucks, (2) a major exploration and development program was completed, reportedly providing sufficient ore reserves to last the company for 20 years, (3) expansion of the ore processing plant was under way, (4) in upgrading the transportation facilities, Robe River was purchasing new locomotives and rehabilitating and extending the rail beds and (5) at the Port of Cape Lambert, changes in the stockpiling system resulted in an increase in shiploading rates and almost doubled the stockpiling capacity. In addition, two new tugs were purchased. The expansion was expected to be completed in 1993, raising production capacity from 24 Mmt to 32 Mmt. Robe River shipped 60,000 mt of sinter fines to Bethlehem Steel Corp.'s Sparrow Point steelworks near Baltimore, its first such delivery to the United States. Robe River's 1991 ore shipments were 24,754 Mmt.

A proposal to abolish export controls on iron ore sales was rejected by the Australian Government. The legislation gave the Federal Government the power

to reject exports of most minerals on any grounds. That power had not been used in the case of iron ore for many years. However, iron ore producers would have liked to see the restriction lifted.

Joint-venture partners CRA Ltd. of Australia and Midrex Corp. of the United States announced plans to further develop the HIs melt direct-iron ore smelting technology. The partners formed Hismelt Corp. Ltd., of Perth, Western Australia, to manage the project. Plans call for the construction of an advanced research and development facility on the site of an old blast furnace in Kwinana, 40 km south of Perth, to be commissioned in early 1993. The pilot plant is expected to cost \$77.5 million. The HIs melt process is a single-stage process that involves the direct smelting of iron ore in a closed, molten-bath reactor. Iron ore fines and coal are injected directly into the molten bath to produce a pig iron equivalent. If the process can be successfully commercialized, it would serve as an alternative to the traditional blast furnace route and would compete against the Corex process owned by Vöest-Alpine Industrieanlagenbau AG of Austria. Like the Corex process, it would eliminate the need for coke ovens, blast furnaces, and sinter plants, thereby bypassing many of the environmental problems associated with cokemaking and sintering. It also uses relatively cheap energy coal rather than higher quality coking coal.

Brazil.—CVRD planned to increase production at its Carajas iron mine to 50 Mmt/yr over a 5-year period, depending on market acceptability. The mine, in northern Brazil, produced 35 Mmt of ore in 1990. Because nearly all of the output from Carajas is exported, CVRD planned to expand its port facilities at Ponta de Madeira. The company invited bids for the construction of a second pier. CVRD ore shipments in 1991 amounted to 112,700 Mmt.

Canada.—CCI closed its Wabush Mine, mill, and pellet plant for 71 days over the summer to reduce both inventory

levels and production. The Wabush complex was in Labrador, Newfoundland.

Mitsubishi Corp., Japan, bought 20% of the Iron Ore Co. of Canada (IOC) from M.A. Hanna Co. of Cleveland. Hanna retained an 8.14% interest in IOC. IOC's other shareholders included Bethlehem Steel (34.5%), National Steel (20%), Dofasco (6.4%), and Labrador Mining and Exploration Co. (11%).

On October 3, Wabush Mines announced plans to downsize its mining and pelletizing operations in eastern Canada by 25%. The downsizing, which took effect at the end of 1991, lowered the production capacity of the joint venture from 6.1 Mmt/yr to 4.6 Mmt/yr. In 1991, the venture shipped 4.79 Mmt of iron ore products from its terminal on the lower St. Lawrence River. All of the material shipped was pellets, with the exception of about 100,000 mt of concentrate that was used as sinter feed. Wabush makes four types of pellets—both standard and fluxed grades, containing either 1% or 2% manganese.

The pelletizing plant is at Pointe Noire, Quebec, on the south shore of Sept-Iles Bay. Feed for the pelletizing plant is railed from the company's Scully Mine at Wabush Lake in Newfoundland. A dedicated 61-km rail line connects the mine to the Quebec North Shore and Labrador Railway at Ross Bay Junction. From Ross Bay Junction, the iron ore concentrate is hauled an additional 385 km via Sept-Iles to Pointe Noire. Wabush is owned by Stelco Inc. (34.50%), Dofasco Inc. (22.10%), Acme Steel Co. (13.75%), Inland Steel Co. (13.75%), Finsider International S.A. (8.89%), and CCI (7.01%). CCI is responsible for the management of the operation.

According to company officials, management's decision to downsize was based on three factors. First, most of the partners in the joint venture needed fewer pellets because of the recession. Second, production costs had risen to an unacceptable level, lowering the competitiveness of the operation. Third, the complex was left with excess capacity in the wake of the bankruptcies of LTV Steel Corp. and Wheeling-Pittsburgh Steel

Corp., two former partners in the venture. Approximately 200 of Wabush's 940 employees were affected by the downsizing.

France.—Usinor Sacilor closed its pig iron operation in December and planned to close its iron mine in 1992.

India.—As part of India's push to expand its ironmaking capacity, a pig iron and a DRI plant began operations, and plans to build others were announced. Indian Iron & Steel Co. commissioned a new pig casting plant at its Burnpur works in West Bengal. The plant had a capacity of 600 mt per day. Lakshmi, an Indian textile machinery manufacturer, formed a joint-venture with the Tamil Nadu Industrial Development Corp. to set up a foundry pig iron plant. The plant, to be either at Salem or Arakonam near Madras, was expected to have an initial production capacity of 150,000 mt/yr, which was to be doubled subsequently. The plant was expected to be fed with iron ore from Belary-Hospet. Tata Iron & Steel Co. planned to build a new pig iron plant in Tamil Nadu in partnership with the Kothari group. The initial capacity of 120,000 mt/yr was to be doubled later. Like the Lakshmi-Tamil Nadu plant, the plant was expected to be supplied by the Belary-Hospet mines in Karnataka. TAMILNADU Sponge Iron Ltd. began production of the first 30,000-mt/yr module at the company's new DRI plant. Work on a second module was to start shortly. The plant was the first to use lignite (brown coal) as the reducing agent. Goldstar Steel & Alloy Ltd. was constructing the country's largest coal-based direct-reduced iron plant at Visakhapatnam in Andhra Pradesh. The plant was to have a production capacity of 220,000 mt/yr from two modules. Goldstar was planning to start commercial production by the end of 1991 and to reach 90% of capacity within 3 years. Thereafter the company planned to build two more modules of 110,000 mt/yr to reach a capacity of 440,000 mt/yr by 1994. Goldstar was licensed to produce 800,000 mt/yr. The Kalyani Group, a

steel producer, planned to set up an 80,000-mt/yr gas-based DRI project at Dharamtar, in the Raigad region of Maharashtra. Construction work on the Kalyani project was scheduled to begin in September with commissioning to take place in 1993. In the same district, Nippon Denro Ispat was constructing a 1-Mmt/yr Midrex DRI plant. Hindustan Electro-Graphites planned to build a 60,000-mt/yr DRI plant in the Borai district of Madhya Pradesh. The plant was expected to use coal-based DR technology and was expected to begin production by the end of the year. Plans called for a second phase of the project to expand to 200,000 mt/yr. Midrex was to construct a DRI plant for Usha Rectifier of New Delhi. The plant was expected to begin production in late 1993 at the rate of 800,000 mt/yr. The plant, to be built at Jagdishpur in the Sultanpur district of Uttar Pradesh, was to be capable of using as much as 100% Indian lump ore as well as a combination of lump and pellets. Usha planned to use India's Bailadila and Banspani Mines and pellets from Kudremukh's operation in Karnataka as sources. The industrial group Prakash Industries of Delhi planned to build a 150,000-mt/yr DRI plant at Champa in Madhya Pradesh. The majority (13 of 18) of the DRI plants under construction around the world as of November 15 were being built in India.

Sail, the state-owned steelmaker, requested approval to construct a 5-Mmt/yr iron ore mine in the Rowghat area of Madhya Pradesh. If completed, the mine would replace the Dalli-Rajhara Mines that were supplying Sail's Bhali steelworks.

Iran.—The National Iranian Steel Co. awarded a \$400 million contract to Kobe Steel for the development of a new mine. The mine, at Chador Nalu in central Iran, was expected to begin production in 1995. Annual output was expected to be 5 Mmt.

Liberia.—Iron mining at the Nimba deposits restarted after being shut down for 1 year by the civil war. Damage to

the mining areas of Yekepa and Todakeh was found to be minimal.

U.S.S.R.—An Australian company, Hancock Resources Ltd., formed a joint venture named Amurstal-Hancock to build a metals complex that would use Australian iron ore. Hancock's joint-venture partner is a number of Russian ferrous enterprises known collectively as Metalurgprom and the Amurstal plant at Komsomlsk-Na-Amurye in the Russian Far East.

Venezuela.—Siderurgica Venezolana S/A (SIVENSA), the largest private Venezuelan steelmaker, inaugurated its 600,000-mt/yr hot-briquetted DRI plant in February. The plant was operated by Siderurgica del Caroni S/A (SIDECAR), a member of SIVENSA'S steelmaking division. Near Peurto Ordaz, the plant was intended to supply hot-briquetted iron (HBI) principally to the adjacent SIVENSA steelworks. The SIDECAR plant was engineered and supplied by an international consortium consisting of Midrex Corp. and Voest-Alpine Industrieanlagenbau.

OUTLOOK

The U.S. iron ore industry is totally dependent on the domestic steel industry for sales. This dependence is not expected to change in the near future. Because of this relationship, the reader is referred to the outlook sections in the "Iron and Steel" and "Iron and Steel Scrap" chapters. Only 7% of the iron ore shipped in 1991 was exported, with virtually all of it being pellets going to steelworks in Ontario. It is difficult for the United States to compete in the world iron ore market because of the country's declining ore grades, the inland location of its mines, and high labor and fuel costs.

For the near term, growth of the U.S. iron ore industry is tied to the growth of the integrated steelworks along the Great Lakes. This growth is expected to average less than 2% per year over the next decade and could very easily be

negative if the recessionary conditions of 1991 are prolonged. The U.S. steel industry is concentrating on making high-value, quality steels, not increasing tonnage. Domestic blast furnace production in the year 2000 is expected to be no more than 60 Mmt. The U.S. iron ore industry has no choice but to focus on making higher quality agglomerates, such as fluxed pellets, that meet much tighter chemical and physical specifications than have been required in the past.

Electric arc furnaces currently account for more than one-third of total crude steel production. Because of advances in steelmaking, steel products now require lower residual alloy content than can be readily achieved with scrap. This indicates a role for imported DRI in the coastal regions of the United States. The growth of gas-based DRI production capacity outside North America has been spectacular in recent years. Although a large part of this growth has occurred in Venezuela, the bulk of the construction has been spread evenly through a myriad of countries that have surplus natural gas. It is too early to tell whether coal-based DRI production will be economically feasible in the United States. No matter how spectacular DRI growth is over the next decade, it will not be able to replace more than a fraction of the world's blast furnace production because of technological restrictions. The blast furnace is expected to remain the mainstay of the iron and steel industries in most developed countries over the next 25 years.

In contrast to the United States, demand for iron ore in other parts of the world is expected to escalate. Some of the greatest growth is being experienced in the Far East. China is currently producing more hot metal than the United States and is modernizing and expanding blast furnace operations throughout the country. Smaller but no less spectacular growth is occurring in the Republic of Korea and in Taiwan. Pohang Iron & Steel Co. Ltd. of Korea now has seven blast furnaces—four at Pohang and three at Kwangyang, with a fourth planned for Kwangyang. Steelworks in the EC have become more competitive in recent years

and should benefit from the growth in steel consumption that is forecasted to occur in Western Europe after the single market takes effect and internal trade barriers are removed. Production of pig iron in Brazil, and to a lesser extent, Argentina and Mexico, consumes much of the Latin American iron ore production. Brazilian pig iron production more than doubled between 1981 and 1989. Price controls reportedly were responsible for the dropoff. Mexican pig iron production has been relatively constant since 1981, ranging from 3.2 Mmt to 3.9 Mmt. Japanese imports of iron ore are not expected to increase dramatically, in spite of the country's dynamic construction and automotive industries, because Japanese companies are moving to higher value products.

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⁴Chamosite is a yellow-green to greenish-gray iron-rich alumino-silicate that forms oolites in sedimentary ironstones. Fine-grained varieties of the alumino-silicate are also found in the groundmass of the ironstone, together with siderite and kaolinite. The mineral, which contains about 30% Fe, is closely related chemically to the chlorites, but has a layered structure more akin to serpentine [$Mg_3Si_4O_{10}(OH)_2$]. Chamosite is a major constituent of the Jurassic ironstones of the English Midlands.

⁵Skillsings' Mining Review. Samarco Adopts Column Flotation at Germano Mine. V. 81, No. 5, Feb. 1, 1992, p. 13.

⁶Lake Carriers' Association (Cleveland, OH). 1990 Annual Report. 78 pp.

⁷Greenwood, J. O. (ed.). Greenwood's Guide to Great Lakes Shipping. Freshwater Press, Apr. 1991, 24 sections.

⁸Skillsings, D. N., Jr. Stelco Opens Its Lake Erie Steel Works. Skillsings' Min. Rev. V. 69, No. 39, Sept. 27, 1980, pp. 10-12.

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TABLE 1
SALIENT IRON ORE STATISTICS

(Thousand metric tons and thousand dollars unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Iron ore (usable,¹ less than 5% manganese):					
Production	47,648	57,515	59,032	56,408	56,761
Shipments	47,983	57,113	58,299	57,010	56,775
Value	\$1,503,087	\$1,716,661	\$1,939,873	\$1,740,925	\$1,674,100
Average value at mines, dollars per ton	31.33	30.06	33.27	30.54	29.49
Exports	5,093	5,285	5,365	3,199	4,045
Value	\$198,254	\$193,796	\$192,796	\$124,076	\$156,242
Imports for consumption	16,849	20,183	19,596	18,054	13,334
Value	\$408,783	\$484,543	\$522,262	\$559,525	\$436,778
Consumption (iron ore and agglomerates)	67,768	83,694	80,447	76,855	64,860
Stocks, Dec. 31:					
At mines ²	2,402	2,957	3,800	3,386	3,421
At consuming plants	16,565	18,005	15,730	15,911	17,612
At U.S. docks ⁴	2,056	2,537	2,171	2,273	2,981
Total ⁵	21,023	23,499	21,701	21,570	24,014
Manganiferous iron ore (5% to 35% manganese):					
Shipments	W	W	W	W	W
World: Production	⁹ 02,737	⁹ 26,047	⁹ 53,294	⁹ 29,023	⁹ 00,840

¹Estimated. ²Revised. W Withheld to avoid disclosing company proprietary data.

³Direct-shipping ore, concentrates, agglomerates, and byproduct ore.

⁴Consumption data for 1988 and 1989 are not entirely comparable with those of previous years owing to changes in data collection.

⁵Excludes byproduct ore. These stocks are not comparable with those of 1982 and earlier years owing to the reclassification of some stocks from the usable to the byproduct category.

⁶Transfer and or receiving docks of Lower Lake ports.

⁷Sum of stocks at mines, consuming plants, and U.S. docks.

TABLE 2
EMPLOYMENT AT IRON ORE MINES AND BENEFICIATING PLANTS, QUANTITY AND TENOR OF ORE PRODUCED, AND AVERAGE OUTPUT PER WORKER-HOUR IN THE UNITED STATES IN 1991, BY DISTRICT AND STATE

District and State	Average number of employees	Worker-hours (thousands)	Production (thousand metric tons)				Average per worker-hour (metric tons)		
			Crude ore	Usable ore	Iron contained (in usable ore)	Iron content, natural (percent)	Crude ore	Usable ore	Iron contained
Lake Superior:									
Michigan	2,070	3,862	38,742	12,645	7,829	61.8	10.03	3.27	2.03
Minnesota	5,599	11,560	143,822	42,991	27,405	63.0	12.44	3.72	2.37
Total or average	7,669	15,422	182,564	55,636	35,234	62.7	11.84	3.60	2.28
Other States ¹	140	244	1,221	1,124	567	56.4	5.02	4.61	2.32
Grand total or average	7,809	15,666	183,785	56,761	35,801	62.6	11.73	3.62	2.29

¹Includes California, Missouri, Montana, New Mexico, South Dakota, Texas, and Utah.

²Data do not add to total shown because of independent rounding.

TABLE 3
CRUDE IRON ORE¹ MINED IN THE UNITED STATES IN 1991, BY
DISTRICT, STATE, AND MINING METHOD

(Thousand metric tons unless otherwise specified and exclusive of ore containing 5% or more manganese)

District and State	Number of mines	Open pit	Underground	Total quantity
Lake Superior:				
Michigan	2	38,742	—	38,742
Minnesota	8	143,822	—	143,822
Total	10	182,564	—	182,564
Other States:				
Missouri	1	—	309	309
Other ²	13	912	—	912
Total	14	912	309	1,221
Grand total	24	183,476	309	183,785

¹Excludes byproduct ore.

²Includes California, Montana, New Mexico, South Dakota, Texas, and Utah.

TABLE 4
USABLE IRON ORE PRODUCED IN THE UNITED STATES IN 1991, BY
DISTRICT, STATE, AND TYPE OF PRODUCT

(Thousand metric tons and exclusive of ore containing 5% or more manganese)

District and State	Direct-shipping ore	Concentrates	Agglomerates ¹	Total quantity
Lake Superior:				
Michigan	78	—	12,567	12,645
Minnesota	224	565	42,203	42,991
Total²	302	565	54,769	55,636
Other States:				
Missouri	—	174	7	181
Other ³	878	66	—	943
Total	878	239	7	1,124
Grand total²	1,180	804	54,777	56,761

¹Data may include pellet chips and screenings.

²Data may not add to totals shown because of independent rounding.

³Includes California, Montana, New Mexico, South Dakota, Texas, and Utah.

TABLE 5
SHIPMENTS OF USABLE IRON ORE¹ FROM MINES IN THE UNITED STATES IN 1991

(Exclusive of ore containing 5% or more manganese)

District and State	Gross weight of ore shipped (thousand metric tons)				Average iron content natural (percent)	Value (thousands)
	Direct- shipping ore	Concentrates	Agglomerates	Total		
Lake Superior:						
Michigan	79	—	12,582	² 12,662	61.8	W
Minnesota	224	605	42,137	42,966	63.0	\$1,157,920
Total reportable or average	<u>303</u>	<u>605</u>	<u>²54,720</u>	<u>55,628</u>	<u>62.7</u>	<u>1,157,920</u>
Other States:						
Missouri	—	171	53	224	68.5	W
Other ³	855	68	—	923	53.4	24,608
Total reportable or average	<u>855</u>	<u>239</u>	<u>53</u>	<u>1,147</u>	<u>58.3</u>	<u>24,608</u>
Total withheld	<u>—</u>	<u>—</u>	<u>—</u>	<u>—</u>	<u>—</u>	<u>491,572</u>
Grand total or average	<u>1,158</u>	<u>844</u>	<u>54,773</u>	<u>56,775</u>	<u>58.3</u>	<u>1,674,100</u>

W Withheld to avoid disclosing company proprietary data; included in "Total withheld."

¹Includes byproduct ore.

²Data do not add to totals shown because of independent rounding.

³Includes Arizona, California, Montana, New Mexico, South Dakota, Texas, and Utah.

TABLE 6
**AVERAGE ANALYSES OF TOTAL TONNAGE¹ OF ALL GRADES OF AGGLOMERATES SHIPPED FROM
 MINES IN THE UNITED STATES**

Year	Quantity (thousand metric tons)	Content (percent) ²					Moisture
		Iron	Phosphorus	Silica	Manganese	Alumina	
SINTER³							
1980	533	44.04	0.136	13.66	0.18	6.04	2.00
1981	423	44.57	.166	13.84	.19	6.34	NA
1982	254	45.94	NA	12.99	NA	6.40	NA
1990	55	61.54	.020	4.87	.17	.36	5.24
1991	440	63.03	.040	4.93	.19	.40	3.50
PELLETS OF ALL TYPES							
1980	63,819	63.42	.022	5.65	.14	.32	2.35
1981	66,994	63.59	.019	5.48	.12	.32	2.38
1982	33,950	63.76	.018	5.38	.10	.30	2.40
1983	43,865	63.64	.018	5.26	.10	.27	2.41
1984	49,549	63.83	.018	5.15	.11	.31	2.47
1985	47,182	63.91	.016	5.12	.10	.28	2.45
1986	40,645	63.90	.015	5.14	.09	.28	2.44
1987	46,337	63.86	.014	5.02	.09	.22	2.04
STANDARD PELLETS							
1988	41,349	64.17	.015	5.08	.11	.21	2.20
1989	36,239	64.46	.013	4.93	.05	.24	1.83
1990	33,626	64.43	.013	4.91	.05	.23	1.91
1991	29,644	64.35	.014	4.88	.04	.25	2.10
FLUXED PELLETS⁴							
1988	13,618	60.71	.017	4.52	.21	.24	2.10
1989	19,755	61.36	.012	4.37	.08	.16	2.12
1990	20,796	61.65	.006	4.25	.03	.12	2.20
1991	23,866	61.46	.006	4.34	.04	.12	1.99

NA Not available.

¹Railroad weight—gross metric tons.

²Natural basis.

³Sinter production at U.S. mines ceased in 1982 and was restarted in 1990.

⁴Ratio of (CaO + MgO)/(SiO₂ + Al₂O₃) is 0.6 or greater.

Source: American Iron Ore Association.

TABLE 7
CONSUMPTION OF IRON ORE¹ AT U.S. IRON AND STEEL PLANTS

(Thousand metric tons)

Year	Iron ore originating areas					Total ²
	U.S. ores		Canadian ores		Foreign ores	
	Great Lakes	Other U.S.	Great Lakes	Other Canada		
1981	61,279	7,207	656	18,377	8,963	96,482
1982	35,789	3,446	76	10,967	5,840	56,119
1983	40,344	2,246	123	11,612	7,876	62,202
1984	44,384	1,680	109	12,130	8,747	67,049
1985	45,089	1,438	1	9,138	9,012	64,678
1986	39,881	1,164	401	7,818	6,905	56,170
1987	44,004	710	—	8,686	7,651	61,051
1988	51,048	1,242	—	9,453	10,122	71,866
1989	51,845	1,710	—	7,473	12,034	73,062
1990	54,341	1,516	—	8,257	9,571	73,685
1991	47,945	660	—	7,229	7,828	63,662

¹Excludes dust, mill scale, and other revert iron-bearing materials added to sinter.

²Data may not add to totals shown because of independent rounding.

Source: American Iron Ore Association.

TABLE 8
CONSUMPTION OF IRON ORE AND AGGLOMERATES AT U.S. IRON AND STEEL PLANTS, BY TYPE OF PRODUCT

(Thousand metric tons)

Type of product	1987	1988	1989	1990	1991
Blast furnaces:					
Direct-shipping ore	2,696	5,155	3,211	2,479	1,918
Pellets	49,500	61,025	61,659	60,512	51,290
Sinter ¹	14,420	15,497	13,664	12,226	10,299
Total ²	66,616	81,676	78,533	75,217	63,507
Steelmaking furnaces:					
Direct-shipping ore	123	194	142	53	33
Pellets	44	88	76	50	40
Sinter ¹	42	—	—	13	5
Total ²	209	282	219	115	78
Grand total ²	66,824	81,958	78,752	75,333	63,585

¹Includes briquettes, nodules, and other.

²Data may not add to totals shown because of independent rounding.

Source: American Iron and Steel Institute.

TABLE 9
U.S. CONSUMPTION OF IRON ORE AND AGGLOMERATES, BY END USE

(Thousand metric tons and exclusive of ore containing 5% or more manganese)

Year	Blast furnaces	Steel furnaces	Sintering plants ¹	Miscellaneous ²	Subtotal integrated iron and steel plants ^{3 4}	Direct-reduced iron for steelmaking ⁵	Nonsteel end uses ⁶	Total
1981	80,022	343	16,028	87	96,482	NA	1,421	97,903
1982	45,898	248	9,062	911	56,119	NA	1,084	57,203
1983	51,610	225	10,134	234	62,202	—	848	63,050
1984	56,072	380	10,353	245	67,049	179	1,222	68,450
1985	55,589	184	8,440	465	64,678	224	1,147	66,049
1986	48,539	97	7,424	110	56,170	244	1,099	57,513
1987	54,614	144	6,270	23	61,051	325	1,049	62,425
1988	63,172	282	8,381	30	71,866	443	1,293	73,602
1989	65,597	336	7,118	10	73,062	487	1,208	74,757
1990	67,551	89	5,809	235	73,685	583	940	75,208
1991	57,381	53	6,212	16	63,662	584	691	64,937

NA Not available.

¹Excludes dust, mill scale, and other revert iron-bearing materials.

²Sold to nonreporting companies or used for purposes not listed.

³Data from American Iron Ore Association.

⁴Data may not add to totals shown because of independent rounding.

⁵U.S. Bureau of Mines estimates based on production reports compiled by Midrex Corp.

⁶Includes iron ore consumed in production of cement and iron ore shipped for use in manufacturing paint, ferrites, heavy media, cattle feed, refractory and weighting materials, and for use in lead smelting. Data from U.S. Bureau of Mines surveys.

TABLE 10
IRON ORE SHIPMENTS FROM U.S. GREAT LAKES PORTS DURING
THE 1991 NAVIGATION SEASON

(March 19, 1990-January 11, 1991)

Port	Date of first shipment	Date of last shipment	Tonnage (thousand metric tons)
Duluth, MN	Mar. 28	Dec. 18	6,868
Two Harbors, MN	Mar. 19	Jan. 06	11,023
Silver Bay, MN ¹	May 03	Dec. 03	1,890
Taconite Harbor, MN	Mar. 27	Dec. 25	7,711
Superior, WI	Mar. 29	Jan. 03	11,391
Marquette, MI	Mar. 30	Jan. 01	5,851
Escanaba, MI	Mar. 20	Jan. 11	5,218
Total			49,952

¹Cyprus Minerals Co. acquired all of the facilities of the defunct Reserve Mining Co. in Aug. 1989, and began shipping from Silver Bay on Apr. 19, 1990. This was the first shipment from Silver Bay since Nov. 1987.

Source: Lake Carriers' Association, 1991 Annual Report.

TABLE 11
GREAT LAKES FREIGHT RATES FOR IRON ORE

Origin	Destination	Dollars per long ton ¹			
		Sept. 25, 1989		July 23, 1990	
		Class X	Other	Class X	Other
Head of the Lakes	Lower lake ports	5.60	6.00	6.00	6.50
Marquette	do.	—	4.98	—	5.40
Escanaba	Lake Erie ports	4.20	4.50	4.50	4.88
Do.	Lower Lake Michigan ports	3.36	3.60	3.60	3.90

¹Excludes winter surcharges for shipments after Dec. 15 and before Apr. 15.

Sources: Cleveland-Cliffs Inc., Interlake Steamship Co., and Skillings' Mining Review.

TABLE 12
UNITED STATES AND CANADIAN IRON ORE SHIPMENTS ON
THE GREAT LAKES

(Thousand metric tons)

Loading district	1987	1988	1989	1990	1991
Lake Superior	41,835	46,098	45,296	46,661	44,734
Lake Michigan	6,032	6,660	5,742	4,987	5,218
Eastern Canada	8,109	9,209	9,480	10,836	8,375
Total ¹	55,976	² 61,966	60,518	62,484	58,327
U.S. flag fleet shipments ³	48,952	55,028	51,799	54,055	49,794
Percent carried by U.S. fleet	87	89	86	87	85

¹Includes transshipments.

²Data do not add to total shown because of independent rounding.

³Includes mill scale, scarfer ore, and slag, in addition to iron ore.

Source: Lake Carriers' Association Annual Reports.

TABLE 13
U.S. EXPORTS OF IRON ORE AND AGGLOMERATES, BY COUNTRY OF DESTINATION

(Thousand metric tons and thousand dollars)

	1987		1988		1989		1990		1991	
	Quantity	Value								
Canada	5,091	198,108	5,277	193,249	5,359	192,334	3,193	123,601	4,032	154,934
India	—	—	(¹)	25	1	59	1	57	(¹)	12
Mexico	1	42	1	62	(¹)	15	1	103	2	75
Netherlands	—	—	(¹)	3	—	—	(¹)	6	—	—
Venezuela	1	95	4	348	(¹)	44	—	—	—	15
Other	(¹)	9	3	109	4	345	4	308	12	1,205
Total ²	5,093	198,254	5,285	193,796	5,365	192,796	3,199	124,076	4,045	156,242

¹Less than 1/2 unit.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 14
U.S. EXPORTS OF IRON ORE AND AGGLOMERATES, BY TYPE OF PRODUCT

Type of product	1989			1990			1991		
	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value ¹ (dollars per ton)	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value ¹ (dollars per ton)	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value ¹ (dollars per ton)
Concentrates	353	13,887	39.39	11	333	31.45	13	733	55.07
Coarse ores	—	—	—	6	213	36.53	(¹)	6	32.26
Fine ores	145	559	3.86	10	346	35.25	10	771	78.65
Pellets	4,852	177,980	36.68	3,018	116,845	38.71	4,017	154,361	38.43
Briquettes	(¹)	22	97.95	—	—	—	1	44	68.43
Other agglomerates	14	230	16.60	136	5,498	40.38	4	283	73.43
Roasted pyrites	1	117	80.17	19	840	45.12	(¹)	45	99.96
Total ²	5,365	192,796	35.94	3,199	124,076	38.78	4,045	156,242	38.62

¹Unit values shown are calculated from unrounded data.

²Less than 1/2 unit.

³Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 15
U.S. IMPORTS OF IRON ORE AND AGGLOMERATES, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1987		1988		1989		1990		1991	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Australia	194	5,141	1,076	16,780	394	5,211	14	584	—	—
Brazil	3,698	64,820	4,935	78,092	5,169	90,885	4,276	90,443	2,481	55,188
Canada	7,981	246,181	9,157	285,961	8,538	292,866	9,344	339,622	7,299	266,496
Chile	636	12,601	139	2,772	61	1,200	138	2,905	103	2,154
India	—	—	126	2,820	59	1,037	—	—	(¹)	2
Liberia	994	13,707	128	1,460	200	2,950	—	—	—	—
Mauritania	412	6,403	522	7,864	594	10,130	666	14,142	459	10,057
Norway	—	—	—	—	40	693	—	—	—	—
Peru	84	1,691	181	2,939	186	4,280	59	1,623	157	3,980
Philippines ²	59	1,575	239	5,432	66	1,622	—	—	—	—
Spain	1	27	—	—	—	—	1	61	1	38
Sweden	139	3,334	88	4,678	57	1,000	54	2,273	51	2,300
Venezuela	³ 2,622	³ 52,889	3,568	75,443	4,232	110,367	3,503	107,848	2,763	94,476
Other	29	413	⁴ 24	⁴ 301	(¹)	21	⁵ (¹)	⁵ 24	22	2,086
Total⁶	16,849	408,783	20,183	484,543	19,596	522,262	18,054	559,525	13,334	436,778

¹Less than 1/2 unit.

²Sinter made from raw materials supplied by Australia, Brazil, and other countries.

³Excludes 18,370 metric tons of sponge iron valued at \$1,849,584, originally reported as iron ore.

⁴Excludes 28,923 metric tons of crude iron sulfate crystals valued at \$318,651, originally reported as iron ore from the Federal Republic of Germany.

⁵Excludes 12 metric tons of iron-oxide-based coloring preparations valued at \$7,542, originally reported as fine ores from China. The 1 ton of material from Namibia that was reported in October was part of a meteorite and was valued at \$10,881.

⁶Data may not add to totals because of independent rounding.

Source: Bureau of the Census.

TABLE 16
U.S. IMPORTS OF IRON ORE AND AGGLOMERATES, BY TYPE OF PRODUCT

Type of product	1989			1990			1991		
	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value ¹ (dollars per ton)	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value ¹ (dollars per tons)	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value ¹ (dollars per ton)
Concentrates	371	7,760	20.93	294	7,733	26.27	398	8,765	22.00
Coarse ores	662	15,566	23.52	545	14,445	26.15	63	1,749	27.54
Fine ores	11,629	297,913	25.62	7,338	181,696	24.76	3,549	87,481	24.75
Pellets	5,628	175,728	31.22	9,875	355,470	36.00	9,317	338,493	36.33
Briquettes	—	—	—	2	165	92.41	(¹)	31	86.01
Other agglomerates	1,186	23,251	19.61	(¹)	14	730.58	2	54	27.49
Roasted pyrites	121	2,045	16.97	(¹)	2	343.60	5	205	44.79
Total³	19,596	522,262	26.65	18,054	559,525	30.99	13,334	436,778	32.75

¹Unit values shown are calculated from unrounded data.

²Less than 1/2 unit.

³Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 17
U.S. IMPORTS OF IRON ORE AND AGGLOMERATES IN 1991,
BY COUNTRY AND TYPE OF PRODUCT

(Thousand metric tons)

Country of origin	Concentrates	Coarse ores	Fine ores	Pellets	Other agglomerates	Roasted pyrites	Total
Brazil	34	40	2,235	170	2	—	2,481
Canada	317	3	2	6,977	(¹)	—	7,299
Chile	47	21	35	—	—	—	103
India	—	—	(¹)	—	—	—	(¹)
Mauritania	—	—	459	—	—	—	459
Peru	—	—	—	155	—	2	157
Sweden	—	—	51	—	—	—	51
Venezuela	—	—	765	1,997	—	—	2,762
Other	(¹)	(¹)	1	19	(¹)	3	23
Total	398	64	3,548	9,317	2	5	²13,334

¹Less than 1/2 unit.

²Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 18
AVERAGE UNIT VALUE FOR
SELECTED IMPORTS OF IRON
ORE AND AGGLOMERATES
IN 1991

Type of product	Country of origin	Average unit value ¹ (dollars per metric ton gross weight)
Coarse ores	Venezuela	—
Fine ores	Brazil	21.48
Do.	Canada	55.73
Do.	Mauritania	21.89
Do.	Venezuela	34.24
Pellets	Brazil	29.97
Do.	Canada	37.17
Do.	Peru	25.13
Do.	Venezuela	34.18

¹Weighted averages of individual Customs values.

Source: Bureau of the Census.

TABLE 19
U.S. IMPORTS OF IRON ORE AND AGGLOMERATES, BY CUSTOMS DISTRICT

(Thousand metric tons and thousand dollars)

Customs district	1987		1988		1989		1990		1991	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Baltimore	5,975	125,887	7,759	183,932	6,062	158,193	3,559	99,849	3,027	89,515
Buffalo	(¹)	30	(¹)	14	—	—	(¹)	2	—	—
Charleston	322	7,580	439	10,088	524	14,858	563	16,629	638	22,293
Chicago	2,007	40,224	1,837	28,820	2,795	52,162	1,654	32,561	1,124	24,708
Cleveland	1,490	54,551	1,401	41,315	1,557	48,401	1,931	66,811	1,641	56,805
Detroit	637	27,196	520	19,607	528	24,773	978	42,185	344	13,679
Houston- Galveston	9	177	62	1,115	28	519	(¹)	18	21	556
Mobile	1,063	22,645	1,595	40,708	2,284	68,830	3,480	121,704	2,571	97,363
New Orleans	1,530	27,230	1,496	22,673	1,845	30,830	1,910	37,308	1,113	26,138
Philadelphia	3,809	103,101	5,031	135,335	3,968	123,112	3,967	141,970	2,826	104,883
Other	7	163	43	937	4	584	12	486	30	836
Total ²	16,849	408,783	20,183	484,543	19,596	522,262	18,054	559,525	13,334	436,778

¹Less than 1/2 unit.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 20
U.S. IMPORTS OF PELLETS, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1989		1990		1991	
	Quantity	Value	Quantity	Value	Quantity	Value
Brazil	400	11,287	509	14,948	170	5,092
Canada	3,146	104,984	7,588	279,961	6,905	256,292
Germany	—	—	—	—	71	3,033
India	59	1,037	—	—	—	—
Peru	159	3,930	59	1,621	155	3,894
U.S.S.R.	—	—	—	—	19	1,940
Venezuela	1,863	54,490	1,719	58,940	1,997	68,243
Total ¹	5,628	175,728	9,875	355,470	9,317	338,493

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 21
PRINCIPAL IRON MINES OF THE WORLD IN 1991¹

Country	Company	Mine	Principal ore minerals
Australia	Goldsworthy Mining Ltd.	Shay Gap and Sunrise Hill, Pilbara, WA	Soft hematite and goethite. ²
Do.	Hammersley Iron Pty. Ltd.	Mount Tom Price, Pilbara, WA	Do.
Do.	do.	Paraburdo, Pilbara, WA	Do.
Do.	Mount Newman Mining Co. Pty. Ltd.	Mount Whaleback, Pilbara, WA	Do.
Do.	do.	Ore Body 29 (Marra Mamba), Pilbara, WA	Do.
Do.	Robe River Iron Associates	Eastern Deepdale, Pannawonica, Pilbara, WA	Pisolitic limonite.
Brazil	Cia. Vale do Rio Doce	Carajas, Para	Hematite and goethite.
Do.	do.	Caue, Minas Gerais	Secondary hematite and goethite derived from itabirite.
Do.	do.	Conceicao-Dois Corregos, Minas Gerais	Do.
Do.	do.	Timbopeba, Ouro Preto, Minas Gerais	Do.
Do.	Ferteco Mineracao SA	Fabrica, Belo Horizonte, Minas Gerais	Do.
Do.	Minas da Serra Geral SA	Capanema, Ouro Preto, Minas Gerais	Do.
Do.	Mineracoes Brasileiras Reunidas SA	Aguas Claras and Mutuca, Belo Horizonte, Minas Gerais	Do.
Do.	Samarco Mineracao SA	Germano and Alegria Sul, Minas Gerais	Do.
Do.	SA Mineracao da Trindade	Alegria, Minas Gerais	Do.
Canada	Iron Ore Co. of Canada	Humphrey, Carol Lake, Labrador	Specular hematite and magnetite.
Do.	Quebec Cartier Mining Co.	Mount Wright, Fermont, Quebec	Specular hematite.
Do.	Wabush Mines	Scully, Wabush, Labrador	Do.
Chile	Cia. Minera del Pacifico SA	El Algarrobo, Vallenar, Region III	Do.
Do.	do.	El Romeral, La Serena, Region IV	Do.
China	Anshan Metallurgical Co.	Dagushan, Liaoning	Magnetite and hematite occurring in taconite.
Do.	do.	Dongganshan, Liaoning	Do.
Do.	do.	Gongchangling, Liaoning	Do.
Do.	do.	Qidashan, Liaoning	Do.
Do.	do.	Yangian, Liaoning	Do.
Do.	Baotou Iron and Steel Co.	Baiyin, Nei Monggol	Magnetite and hematite-martite.
Do.	Benxi Iron and Steel Co.	Nanfen and Waitoushan, Liaoning	Magnetite and hematite occurring in taconite.
Do.	Hainan Mining Co.	Shilu, Hainan	Hematite and magnetite.
Do.	Maanshan Iron and Steel Co.	Gushan and Nanshan, Anhui	Titaniferous magnetite.
Do.	do.	Taochong, Anhui	Do.
Do.	Panzhihua Mining Co.	Lanjian and Zhujiabaobao, Sichuan	Do.
Do.	Shoudu Iron and Steel Co.	Dashine, Beijing Municipality	Magnetite occurring in quartzite.
Do.	do.	Shuichang, Beijing Municipality	Do.
Do.	Wuhan Iron and Steel Co.	Chengchao, Hubei	NA.
Do.	do.	Daye Complex, Huangshi City, Hubei	Magnetite, hematite, chalcopyrite, and pyrite.

See footnotes at end of table.

TABLE 21—Continued
PRINCIPAL IRON MINES OF THE WORLD IN 1991¹

Country	Company	Mine	Principal ore minerals
China—Continued	Wuhan Iron and Steel Co.	Jinshandian, Hubei	NA.
Do.	do.	Lingxiang, Hubei	NA.
France	Arbed SA	Ferdinand and Montrouge, Lorraine Basin	Oolitic limonite.
India	Chowgule & Co. Pvt. Ltd. (et al.) ³	Goa	Hematite and magnetite.
Do.	Indian Iron and Steel Co. Ltd	Gua and Manoharpur, Singhbhum district, Bihar	Hematite.
Do.	Kudremukh Iron Ore Co. Ltd	Kudremukh, Chikmagalur district, Karnataka	Magnetite in taconite.
Do.	National Mineral Development Corp. Ltd.	Bailadila, Bastar district, Madhya Pradesh	Hematite.
Do.	do.	Donimalai, Bellary district, Karnataka	Do.
Do.	Steel Authority of India Ltd.	Kiriburu and Bolani, Singhbhum district, Bihar	Do.
Do.	do.	Rajhara and Dalli, Durg district, Madhya Pradesh	Do.
Do.	do.	Kendujhar and Sundargarh districts, Orissa	Do.
Do.	Tata Iron and Steel Co. Ltd	Noamundi, Singhbhum district, Bihar	Do.
Do.	do.	Kendujhar district, Orissa	Do.
Korea, North	Government owned	Musan, Chongjin	Magnetite.
Liberia	Bong Mining Co.	Zaweah Pits and Bong Peak, Bong County	Hematite and magnetite associated with itabirite.
Do	LAMCO Joint Venture ⁴	Nimba, Gbahrn and Tokadeh Pits, Yekepa	Hematite and goethite.
Mauritania	Societe Nationale Industrielle et Miniere	Tazadit (et alia), Kedia D'Idjil	Hematite.
Do.	do.	El Rhein Guelb, Zouerate	Magnetite in taconite.
South Africa, Republic of	ISCOR Ltd.	Sishen, Griqualand West, Cape Province	Hematite.
Do.	do.	Thabazimbi, Transvaal	Hematite and goethite.
Sweden	Luossavaara-Kiirunavaara AB	Kiruna, Lapland	Magnetite.
Do.	do.	Malmberget, Lapland	Do.
U.S.S.R.	Government owned	Bakal, Ural Mountains, RSFSR	Sideroplesite and pistomesite (magnesian siderite).
Do.	do.	Blagodot, Ural Mountains, RSFSR	Magnetite and martite
Do.	do.	Gora Vysokaya, Ural Mountains, RSFSR	Do.
Do.	do.	Kachar, Turgay Depression, Kazakh SSR	Magnetite.
Do.	do.	Kaz, Gornaya Shoriya, RSFSR	Do.
Do.	do.	Kachkanar/Gusevogorsk, Ural Mountains, RSFSR	Titaniferous magnetite.
Do.	do.	Korshunika, Angara-Ilim, Irkutsk Oblast, RSFSR	Magnesian magnetite.
Do.	do.	Kostomuksha, Lake Kujto, Karelia ASSR	Magnetite.
Do.	do.	Kovdor, Kola Peninsula, RSFSR	Do.
Do.	do.	Kremenchug (four complexes), Ukrainian SSR	Magnetite, martite-hematite, and siderite.

See footnotes at end of table.

TABLE 21—Continued
PRINCIPAL IRON MINES OF THE WORLD IN 1991¹

Country	Company	Mine	Principal ore minerals
U.S.S.R.—Continued	Government owned	Krivoy Rog (six complexes), Ukrainian SSR	Martite-hematite, limonite, and magnetite.
Do.	do.	Lebedinsk, Kursk Magnetic Anomaly, RSFSR	Magnetite and hematite.
Do.	do.	Lisakovsk, Turgay Depression, Kazakh SSR	Oolitic limonite and siderite.
Do.	do.	Magnitnaya Gora, Ural Mountains, RSFSR	Magnetite and martite.
Do.	do.	Mikhaylovsk, Kursk Magnetic Anomaly, RSFSR	Martite-hematite.
Do.	do.	Olenegorsk, Kola Peninsula, RSFSR	Magnetite and hematite.
Do.	do.	Sheregesh and Tashtagol, Gornaya Shoriya, RSFSR	Magnetite.
Do.	do.	Sokolov-Sarbayk, Rudnyy, Kazakh SSR	Do.
Do.	do.	Stoylensk, Kursk Magnetic Anomaly, RSFSR	Martite-hematite.
Do.	do.	Yakovlevo, Kursk Magnetic Anomaly, RSFSR	Do.
United States	Empire Iron Mining Partnership	Empire, Marquette Range, Palmer, MI	Magnetite occurring in taconite.
Do.	Eveleth Mines	Thunderbird, Mesabi Range, Eveleth, MN	Do.
Do.	Hibbing Taconite Co.	Hibbing, Mesabi Range, Hibbing, MN	Do.
Do.	LTV Steel Mining Co.	Erie, Mesabi Range, Hoyt Lakes, MN	Do.
Do.	National Steel Pellet Co.	NSPC Project, Mesabi Range, Keewatin, MN	Do.
Do.	Tilden Magnetite Partnership	Tilden, Marquette Range, Ishpeming, MI	Magnetite and hematite occurring in taconite.
Do.	USX Corp.	Minntac, Mesabi Range, Mountain Iron, MN	Magnetite occurring in taconite.
Venezuela	C.V.G. Ferrominera del Orinoco CA	Cerro Bolivar, Piar district, Bolivar State	Hematite and goethite.
Do.	do.	San Isidro, Piar district, Bolivar State	Do.
Do.	do.	Los Barrancos, Piar district, Bolivar State	Do.

NA Not available.

¹Includes only those mines, complexes, or mining groups that had shipments of at least 4.0 million metric tons in 1989, 1990, or 1991.

²The mixed ore is considered to be the result of "hematite enrichment."

³Other Goan shippers include Damodar Mangalji & Co. (Pvt.) Ltd., V.S. Dempo & Co. (Pvt.) Ltd., Sociada de Fomento Industrial (Pvt.) Ltd., Minerals & Metals Trading Corp. of India Ltd., Orient Goa (Pvt.) Ltd., V.M. Salgaocar & Brother Ltd., A.V. Sarmalkar, and Sesa Goa Ltd.

⁴Liberian Mining Corp. (LIMINCO) assumed full control of the LAMCO Joint Ventura in late 1989. The Mining complex was being operated for LIMINCO by a subsidiary of the African Mining Consortium Ltd. Mining operations and shipments were interrupted by the civil war, but resumed at a reduced rate in Apr. 1991.

TABLE 22
IRON ORE, IRON ORE CONCENTRATES, AND IRON ORE AGGLOMERATES: WORLD PRODUCTION, BY COUNTRY¹

(Thousand metric tons)

Country ²	Gross weight ³					Metal content ⁴				
	1987	1988	1989	1990	1991 ⁵	1987	1988	1989	1990	1991 ⁵
Albania ⁵	972	1,067	1,179	930	800	430	470	520	410	350
Algeria	3,382	3,118	2,748	2,939	2,500	1,691	1,559	1,374	1,470	1,250
Argentina	850	1,037	1,017	992	980	450	550	540	525	520
Australia ⁶	101,748	96,084	105,810	110,508	117,134	64,798	61,244	67,313	69,766	68,732
Austria	3,061	2,301	2,410	2,300	2,083	954	727	740	720	649
Bolivia	7	34	14	125	102	5	21	9	79	64
Brazil	134,497	146,008	157,900	155,200	155,000	89,134	97,139	105,100	103,200	103,000
Bulgaria	1,857	1,826	1,613	1,079	1,000	559	528	482	321	300
Canada ⁸	37,702	39,934	39,445	35,670	35,961	23,882	24,268	23,971	22,472	22,655
Chile	6,637	7,710	8,761	8,248	8,414	4,380	5,089	5,478	5,035	5,136
China ⁹	113,000	117,000	122,000	117,000	119,000	56,500	58,500	61,000	58,500	59,500
Colombia	614	609	573	628	650	282	280	260	283	295
Czechoslovakia	1,798	1,773	1,780	1,831	1,800	462	440	470	480	470
Egypt	2,048	2,112	2,562	2,405	2,400	1,100	1,000	1,500	1,500	1,250
Finland ¹⁰	648	556	—	—	—	588	360	—	—	—
France	11,267	9,872	9,319	8,729	7,472	3,511	3,119	2,945	2,793	2,316
Germany: Western states	247	70	102	80	115	68	10	14	12	17
Greece ⁵	1,083	1,573	2,013	2,000	1,500	423	640	820	800	600
India	51,018	49,961	51,434	54,579	57,638	31,937	31,226	32,198	33,600	35,500
Indonesia	194	203	143	145	150	113	118	83	84	85
Iran ¹¹	1,692	2,005	2,296	3,240	4,890	900	1,100	1,300	1,800	2,700
Japan	266	97	41	34	31	167	61	25	21	19
Korea, North ⁸	8,500	9,000	9,500	9,500	10,000	4,000	4,200	4,400	4,400	4,700
Korea, Republic of	470	390	334	298	300	263	218	187	180	180
Liberia	13,742	12,767	11,700	4,050	1,100	8,520	7,910	7,087	2,490	710
Malaysia	161	132	193	344	375	98	81	118	210	229
Mauritania	9,002	9,780	12,114	11,420	11,000	5,851	6,357	7,874	7,250	7,150
Mexico ¹²	7,523	8,431	8,141	8,073	9,634	4,965	5,564	5,373	5,328	6,359
Morocco	210	114	176	148	97	128	70	107	90	59
New Zealand ¹³	2,294	2,351	2,367	2,296	2,060	1,300	1,300	1,300	1,300	1,100
Norway	3,141	2,644	2,358	2,081	2,209	2,042	1,719	1,528	1,353	1,436
Peru	5,019	4,171	4,460	3,246	2,150	3,305	2,839	2,923	2,147	1,450
Poland	6	6	7	2	—	2	2	2	1	—
Portugal ¹⁴	27	33	13	12	12	9	8	6	4	4
Romania	2,281	2,482	2,482	2,002	1,800	250	260	260	250	220
South Africa, Republic of ¹⁵	22,008	25,248	29,958	30,291	29,069	14,297	16,461	19,461	19,689	19,000
Spain ¹⁶	4,492	4,212	4,566	3,030	3,900	2,124	1,925	2,120	1,394	1,790
Sweden	19,636	20,440	21,763	19,877	20,000	12,809	13,393	14,124	12,901	13,046
Thailand	97	99	177	129	240	53	55	98	71	132
Tunisia	295	325	280	291	295	159	175	140	145	145
Turkey	5,366	5,481	4,518	5,050	5,400	2,881	2,983	2,450	2,750	2,900
U.S.S.R.	250,874	249,754	241,348	236,000	200,000	138,216	138,217	134,789	132,000	110,000
United Kingdom	263	224	34	55	50	58	49	8	12	11
United States ¹⁶	47,648	57,515	59,032	56,408	56,596	30,526	36,468	37,413	35,695	35,333
Venezuela	17,782	18,932	18,390	20,365	21,222	11,670	12,340	12,016	12,655	13,187

See footnotes at end of table.

TABLE 22—Continued
IRON ORE, IRON ORE CONCENTRATES, AND IRON ORE AGGLOMERATES: WORLD PRODUCTION, BY COUNTRY¹

(Thousand metric tons)

Country ²	Gross weight ³					Metal content ⁴				
	1987	1988	1989	1990	1991 ⁵	1987	1988	1989	1990	1991 ⁵
Yugoslavia	5,983	5,545	5,080	4,132	2,574	1,764	1,844	*1,305	*1,578	900
Zambia	1	(¹⁷)	(¹⁷)	1	1	1	(¹⁷)	(¹⁷)	(¹⁷)	(¹⁷)
Zimbabwe	1,328	*1,021	1,143	1,260	*1,136	*820	*630	*690	*730	700
Total	*902,737	*926,047	*953,294	929,023	900,840	*528,445	*543,517	*561,921	*548,494	526,149

¹Estimated. ²Revised.

³Table includes data available through July 9, 1992.

⁴In addition to the countries listed, Cuba and Vietnam may produce iron ore, but definitive information on output levels, if any, is not available.

⁵Insofar as availability of sources permits, gross weight data in this table represent the nonduplicative sum of marketable direct-shipping iron ores, iron ore concentrates, and iron ore agglomerates produced by each of the listed countries. Concentrates and agglomerates produced from imported iron ores have been excluded under the assumption that the ore from which such materials are produced has been credited as marketable ore in the country where it was mined.

⁶Data represent actual reported weight of contained metal or are calculated from reported metal content. Estimated figures are based on latest available iron content reported, except for the following countries for which grades are U.S. Bureau of Mines estimates: Albania, Hungary, and North Korea.

⁷Nickeliferous iron ore.

⁸Dry weight.

⁹Reported figure.

¹⁰Series represent gross weight and metal content of usable iron ore (including byproduct ore) actually produced, natural weight.

¹¹U.S. Bureau of Mines estimate of China's usable iron ore production. The ore grade of the series is equivalent to 50% Fe content to provide data approximately comparable with world market production. Bureau estimates, run-of-mine ore in China averages only about 35% Fe. Production of crude ore, as reported by The Year Book of Iron and Steel Industry of China was as follows, in thousand metric tons: 1987—161,430 (revised); 1988—167,700 (revised); 1989—171,850 (revised); 1990—168,300 (revised, estimated); 1991—170,000 (estimated).

¹²Includes magnetite concentrate, pelletized iron oxide (from roasted pyrite), and roasted pyrite (purple ore).

¹³Data are for year beginning Mar. 21 of that stated.

¹⁴Gross weight calculated from reported iron content based on grade of 66% Fe.

¹⁵Concentrates from titaniferous magnetite beach sands.

¹⁶Includes manganese iron ore.

¹⁷Includes magnetite ore as follows, in thousand metric tons: 1987—4,979; 1988—5,492; 1989—6,594; 1990—5,613; 1991—5,658.

¹⁸Includes byproduct ore.

¹⁹Less than 1/2 unit.

TABLE 23
SELECTED PRICES FOR IRON ORE IN THE JAPANESE MARKET

(F.o.b. shipping port basis. U.S. cents per dry long ton of iron unless otherwise specified)

Country and producer	Ore type	(April 1-March 31)			
		Fiscal year 1988	Fiscal year 1989	Fiscal year 1990	Fiscal year 1991
Australia:					
Hamersley Iron Pty. Ltd. and Mount Newman Mining Co. Pty. Ltd.	Lump ore	28.78	33.76	39.15	41.48
Do.	Fines	23.68	26.76	31.03	33.49
Robe River Iron Associates	do.	20.51	23.18	26.88	29.01
Savage River Mines Ltd	Pellets	36.46	42.77	46.63	(¹)
Brazil:					
Cia. Nipo-Brasileira de Pelotizacao (Nibrasco)	do.	38.54	45.20	49.28	(¹)
Cia. Vale do Rio Doce (Carajas)	Fines	21.23	23.99	27.82	30.03
Do.	Lump ore	24.92	30.99	35.94	38.08
Cia. Vale do Rio Doce (Itabira)	do.	22.24	25.60	29.69	31.46
Mineraes Brasileiras Reunidas S.A.	do.	21.77	25.05	29.05	30.78
Do.	Fines	21.73	24.46	28.36	30.61
Samarco Mineracao S.A.	Pellet feed	17.46	19.73	22.88	24.70
Canada: Iron Ore Co. of Canada (Carol Lake)	Concentrates	20.25	22.88	26.53	28.63
Chile:					
Minera del Pacifico S.A. (El Algarrobo)	Pellets	32.98	40.73	44.40	(¹)
Minera del Pacifico S.A. (El Romeral)	Fines	16.44	18.58	21.55	23.26

See footnotes at end of table.

TABLE 23—Continued
SELECTED PRICES FOR IRON ORE IN THE JAPANESE MARKET

(F.o.b. shipping port basis. U.S. cents per dry long ton of iron unless otherwise specified)

Country and producer	Ore type	(April 1-March 31)			
		Fiscal year 1988	Fiscal year 1989	Fiscal year 1990	Fiscal year 1991
India:					
Minerals and Metals Trading Corp. (Bailadila)	Lump ore	27.75	32.55	37.74	39.99
Do.	Fines	22.75	25.71	29.81	32.17
Liberia: LAMCO Joint Venture Operating Co	do.	18.58	21.00	(¹)	(¹)
Peru: Empresa Minera del Hierro del Peru S.A.	Pellets	27.59	(¹)	(¹)	(¹)
South Africa, Republic of:					
South African Iron and Steel Industrial Corp. Ltd	Lump ore	² 22.21	² 26.05	² 30.21	32.01
Do.	Fines	² 18.03	² 20.37	² 23.62	25.49

¹No quotation published.

²Price per dry metric ton unit.

Source: The TEX Report (Tokyo), v. 23, No. 5375, Apr. 8, 1991, p. 12.

TABLE 24
IRON ORE: WORLD PELLETIZING CAPACITY, BY CONTINENT AND COUNTRY

	Number			Rated capacity (million metric tons, gross weight)
	Sites	Plants ¹	Units	
North America:				
Canada	5	6	13	26.44
Mexico	5	6	6	9.50
United States ²	10	18	50	66.55
Total	<u>20</u>	<u>30</u>	<u>69</u>	<u>102.49</u>
South America:				
Argentina	1	1	4	1.00
Brazil	3	8	8	24.30
Chile	1	1	1	4.00
Peru	1	2	2	3.20
Venezuela	1	1	2	6.60
Total	<u>7</u>	<u>13</u>	<u>17</u>	<u>39.10</u>
Europe:				
Belgium-Luxembourg ³	1	1	1	.80
Czechoslovakia	1	1	1	.25
Netherlands ³	1	1	1	3.80
Norway ⁴	2	3	3	3.20
Sweden ³	3	3	4	10.40
Turkey	1	1	1	1.30
U.S.S.R. ⁵	7	13	NA	80.00
Yugoslavia ⁷	1	1	1	.60
Total	<u>17</u>	<u>24</u>	<u>NA</u>	<u>100.35</u>
Africa:				
Liberia ⁸	1	1	1	3.00
Morocco ⁹	1	1	1	.85

See footnotes at end of table.

TABLE 24—Continued

IRON ORE: WORLD PELLETIZING CAPACITY, BY CONTINENT AND COUNTRY

	Number			Rated capacity (million metric tons, gross weight)
	Sites	Plants ¹	Units	
Africa—Continued:				
Nigeria ³	1	1	1	1.45
South Africa, Republic of	1	1	1	.60
Total	4	4	4	5.90
Asia:				
Bahrain ³	1	1	1	4.00
China ⁶	4	4	NA	2.50
India ¹⁰	1	1	1	2.00
Iran	1	1	1	2.50
Japan ³	1	2	2	4.40
Total	8	9	NA	15.40
Oceania: Australia ¹¹	2	2	6	4.00
World total	58	82	NA	267.24

NA Not available.

¹Staged additions are treated at some mining complexes as if they were separate plants. Site data excludes plants that have had no production since 1982. Plants that produced after 1979, but have been continuously idle since 1982, are cited in the footnotes because they could be reactivated at some reasonable cost.

²The total for the United States includes the newer part of the E. W. Davis Works at Silver Bay, MN, but not the idled plant owned by Cleveland-Cliffs Inc. at Republic, MI. Cyprus Minerals Co. acquired the cannibalized Silver Bay facility in Aug. 1989 and resumed production in Jan. 1990. Cleveland-Cliffs has been considering reopening its 1 Mmt/yr Republic plant, which has been on care and maintenance since 1981.

³Pellets produced from imported direct-shipping ores and/or concentrates.

⁴The older of the two plants, operated by A/S Sydvaranger at Kirkenes, has been idle since 1986. In addition, the 0.50 Mmt/yr plant operated by Norsk Jernverk at Mo-i-Rana was shut down in Jan. 1987 for an indefinite period, leaving only one plant in Norway on-line.

⁵In early 1988, the capacity of the Svappavaara plant was upgraded from 2.8 to 3.5 Mmt/yr. The 0.3 Mmt/yr steel belt plant at Malmberget is used for both research and development purposes as well as ordinary production.

⁶Based on incomplete information.

The Skopje plant operated by Rudnici i Zelezara was recently idled.

⁷Excludes the No. 1 pelletizing plant (capacity of 2.4 Mmt/yr) of the Bong Mining Co. The No. 1 plant has been idle since 1980.

⁸The Nador plant operated by Societe d'Exploitation des Mines du Rif (SEFERIF) has been idle for several years.

⁹There is an additional plant with a capacity of 1.8 Mmt/yr at Mandovi in Goa, but it has been closed since 1982. The owner was planning to reopen the facility using high-grade blue dust from the Bellary Hospet area of Karnataka as feed.

¹⁰There is an additional plant with a capacity of 3.0 Mmt/yr at Dampier in Western Australia, but it has been closed since 1980.

Sources: Association of Iron Ore Exporting Countries (Geneva, Switzerland), Commodities Research Unit Ltd. (London, United Kingdom), International Iron and Steel Institute (Brussels, Belgium), Metal Bulletin Books Ltd. (Surrey, United Kingdom), Roskill Information Services Ltd. (London, United Kingdom), United Nations Commission on Trade and Development (UNCTAD), UNCTAD Trust Fund Project on Iron Ore Information, and U.S. Bureau of Mines.

FIGURE 1
U.S. IRON ORE PRODUCTION AND IMPORTS FOR CONSUMPTION

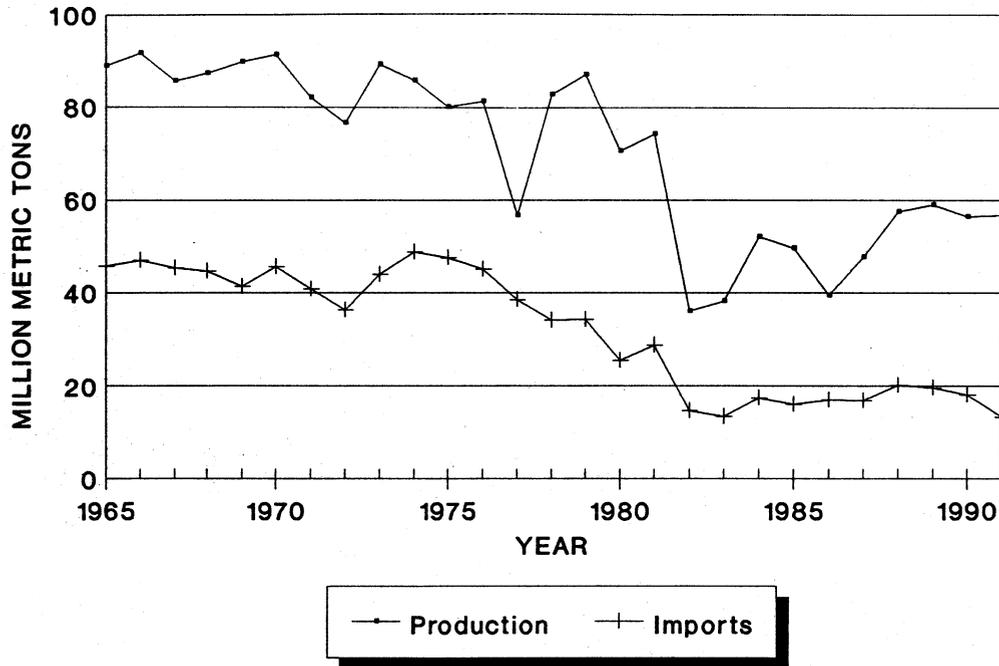


FIGURE 2
CONSUMPTION OF IRON ORE IN U.S. SINTERING PLANTS

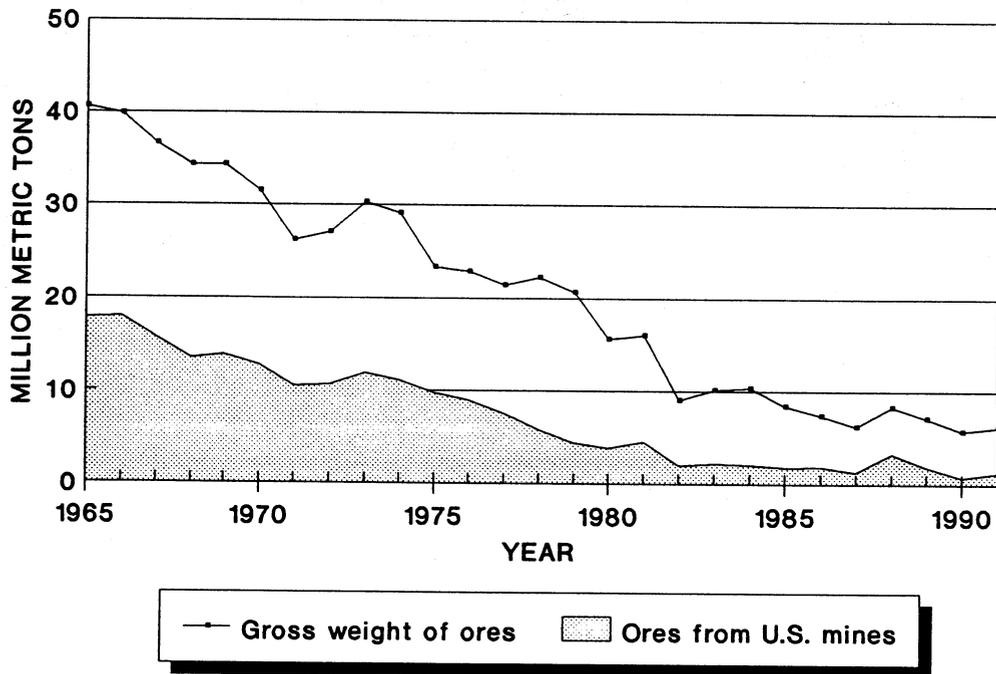


FIGURE 3
WORLD DIRECT-REDUCED IRON PRODUCTION

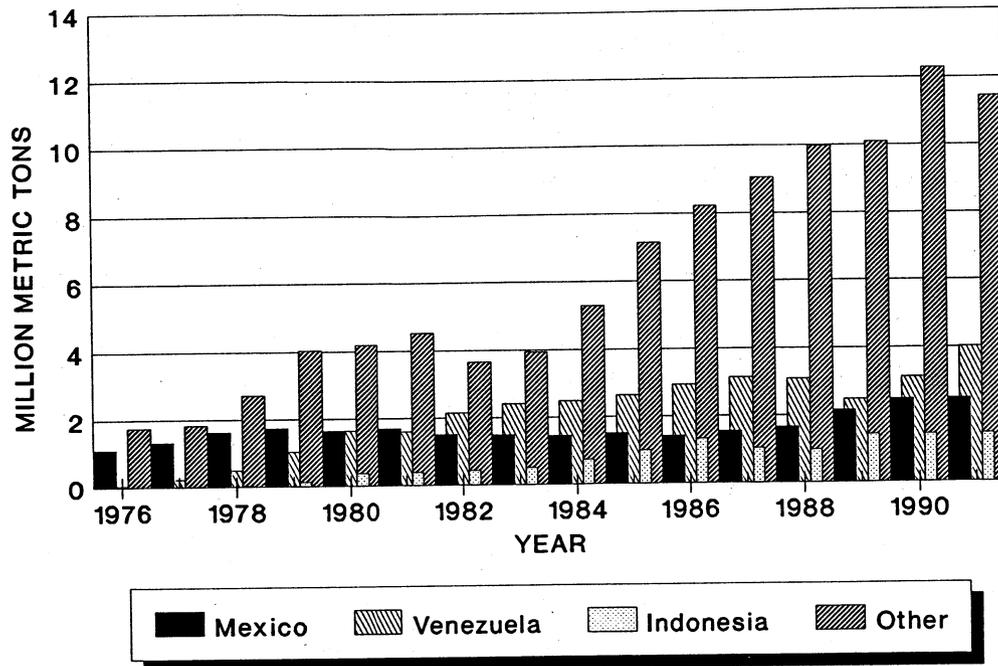
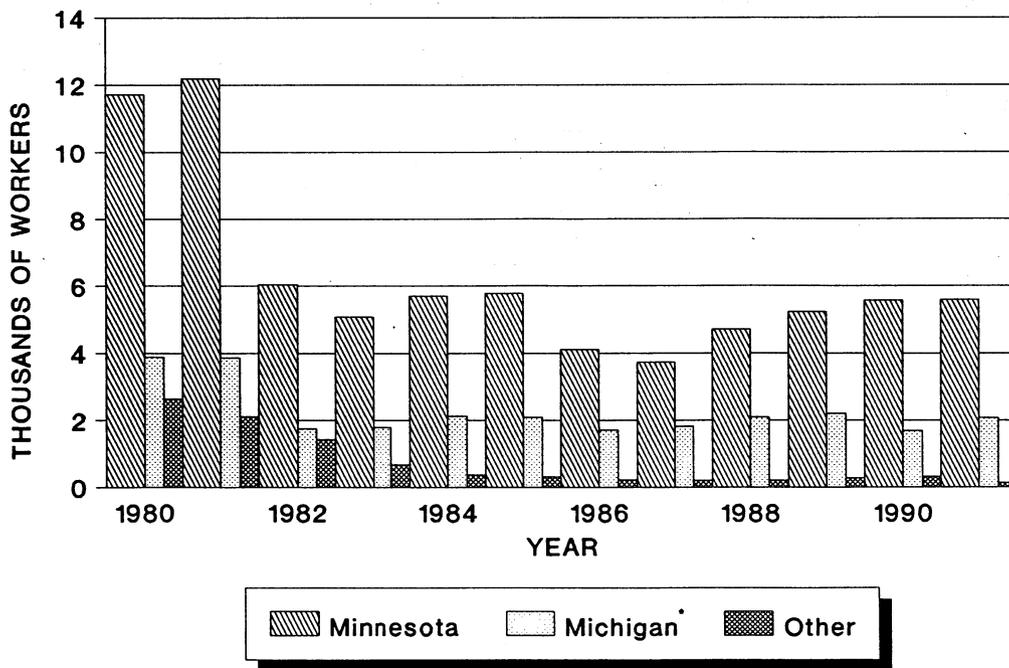
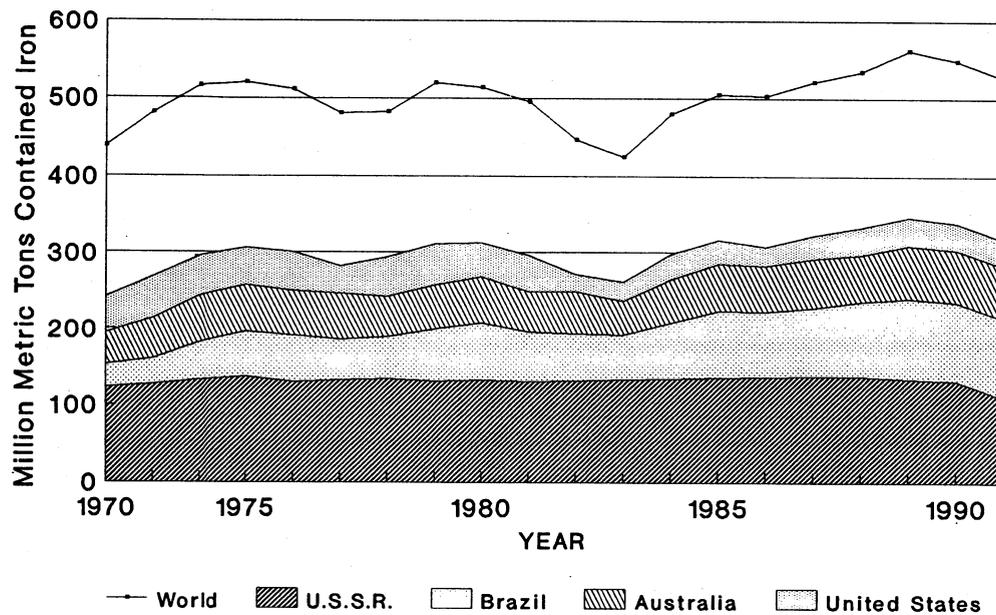


FIGURE 4
EMPLOYMENT AT IRON MINES AND BENEFICIATING PLANTS



* Includes workers in Wisconsin for years prior to 1984.

FIGURE 5
 COMPARISON OF U.S. IRON ORE PRODUCTION WITH TOTAL PRODUCTION FOR THE WORLD



IRON OXIDE PIGMENTS

By David A. Templeton

Mr. Templeton, a physical scientist with 4 years U.S. Bureau of Mines experience, has been the commodity specialist for iron oxide pigments for 1 year. Domestic survey data were prepared by Gloria Peebles, statistical data assistant; and international data tables were prepared by Audrey Wilkes.

DOMESTIC PRODUCTION

According to the U.S. Bureau of Mines, mine production and sales of crude iron oxide pigments (IOP) in 1991 edged upward to 34,083 and 40,220 metric tons, respectively. Sales of synthetic iron oxide pigments dropped to 117,224 tons, a level not seen since the period between 1984-86. Imports for consumption held steady at the 34,000-ton level, and exports returned to the 1987-88 level of 20,000 tons after a 2-year dip to the 10,000-ton level.

Data in table 2 regarding sales of finished synthetic pigments have been rearranged to show the three primary pigments. Hitherto, only the red pigments stood alone in the published figures, and black and yellow were each published as combinations with other categories (brown and mixtures/specialties, respectively). The extraneous data have been combined into one number (see under brown), and black and yellow now stand alone along with red. (See table 2.)

Industry Structure

The many changes affecting the pigment and iron oxide industries in 1991 included acquisitions, plant closings, and bankruptcy. Harcros Pigments, Inc. purchased Northern Pigment of Toronto, Canada, for \$C17 million, thus bringing its total number of pigment-producing plants to four. Conversely, Columbian Chemicals Co. shuttered its predominantly red-producing plant in Monmouth Junction, NJ, at midyear,

thereby leaving it with a sole plant in St. Louis, MO.

Changes in the regenerator oxide industry included the exit of two companies and the entrance of a third. Perox, which had previously produced iron oxide at two separate plants via regenerating pickle liquor, filed for chapter 7 bankruptcy in February. The Fairfield, AL, plant is now owned and operated by U.S. Steel, and Sharon Steel retains ownership of its plant in Sharon, PA, but contracted its operation to International Steel Services, Inc., of Pittsburgh. Lehi, UT-based Peteco Inc. folded in September when Geneva Steel switched to a new finishing method that produces a lime-white powder rather than the red precipitator dust formerly used as pigment for cinder blocks. Magnetics International, Inc., a division of Inland Steel Industries, Inc., began treating spent pickle liquors at a new plant in Burns Harbor, IN. The state-of-the-art facility, which houses two spray roasters, was designed specifically to produce high-quality ferrite powders while regenerating acid in the process, as opposed to typical plants that focus on the latter.

The magnetic iron oxide business introduced a new domestic player as well. Three of the four plants that Harcros purchased from Pfizer Inc. produce this material, one solely (Valparaiso, IN) and two ancillary to pigment production (Easton, PA, and East St. Louis, IL). Ishihara Sangyo Kaisha (ISK) purchased the Valparaiso plant outright and reportedly will take all production from the Easton and East St. Louis plants on a toll basis. ISK joins U.S. producers 3M Co. and Magnox, Inc., in supplying the

magnetic media markets with the raw material for audiotapes and videotapes, computer disks, etc.

Effective January 1, 1992, Bayer AG, the German parent of Mobay Corp. et al., grouped all of its U.S. business concerns under the name Miles Inc. (As this is a 1991 report, table 3 does not reflect this change.) Pigment-related business will be handled by the Miles Industrial Chemicals Div.

World Review

Savage Resources Ltd. continued exploration of a promising deposit in northwest Tasmania near Savage River Township. The deposit, discovered in 1987, has been extensively drilled, and three distinct ore bodies have been identified. Portions of each deposit comprise the HT Ocher Site, which has been assessed to contain 350,000 tons of brown, yellow, and red iron oxide pigments (175-, 130-, and 45-thousand tons, respectively). Having delineated sufficient resources to satisfy the original goal of 10,000 tons annual production for 10 years, efforts to produce a refined pigment continue.

Oakville, Ontario-based Stewart Lake Resources Inc. neared completion of a feasibility study addressing the production of IOP from a worked deposit near Sofia, Bulgaria. The Kremikovtsi deposit was reported to contain black, brown, ocher, and red pigments, but a wider selection will probably be produced via blending.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications
Iron Ore. Ch. in Minerals Yearbook, annual.

Other Sources
 American Paint and Coatings Journal.
 Modern Paint and Coatings.

TABLE 1
 SALIENT U.S. IRON OXIDE PIGMENTS STATISTICS

		1987	1988	1989	1990	1991
Mine production	metric tons	31,816	30,747	36,661	32,421	34,083
Crude pigments sold or used	do.	38,803	39,711	40,202	37,071	40,220
Value	thousands	\$3,598	\$3,815	\$4,561	\$4,615	\$4,485
Finished pigments sold	metric tons	124,293	126,640	127,665	*125,031	117,224
Value	thousands	\$136,427	\$134,325	\$134,567	*\$139,135	\$132,886
Exports ¹	metric tons	20,184	21,966	9,966	*9,535	20,606
Value	thousands	\$31,689	\$33,014	\$15,700	*\$18,694	\$33,813
Imports for consumption ¹	metric tons	38,394	38,929	36,669	*34,096	34,725
Value	thousands	\$20,680	\$27,128	\$30,540	*\$37,276	\$39,360

¹Revised.

¹Data reflect conversion to the Harmonized Tariff Schedule, effective Jan. 1, 1989.

TABLE 2
FINISHED IRON OXIDE PIGMENTS SOLD BY PROCESSORS IN THE
UNITED STATES, BY KIND

Kind	1990		1991	
	Quantity (metric tons)	Value (thousand dollars)	Quantity (metric tons)	Value (thousand dollars)
Natural:				
Black: Magnetite	W	W	W	W
Brown: Iron oxide	W	W	W	W
Umbers:				
Burnt	W	W	W	W
Raw	W	W	W	W
Red:				
Iron oxide ¹	² 26,830	² 4,736	25,590	5,176
Sienna, burnt	W	W	W	W
Yellow:				
Ocher	W	W	W	W
Sienna, raw	W	W	W	W
Undistributed	² 21,814	² 10,007	23,579	10,839
Total	<u>²48,644</u>	<u>²14,743</u>	<u>49,169</u>	<u>16,015</u>
Synthetic:				
Black:				
Iron oxide	25,769	41,030	15,317	23,089
Brown:				
Iron oxide	³ (⁴)	³ (⁴)	³ 7,998	³ 15,067
Red:				
Iron oxide	32,489	54,238	28,346	50,535
Yellow:				
Iron oxide	¹ 18,130	¹ 29,124	16,396	28,180
Mixtures of natural and synthetic:				
Iron oxides	⁵ (⁶)			
Other: Specialty oxides	⁵ (⁶)			
Total⁵	<u>76,387</u>	<u>124,392</u>	<u>68,055</u>	<u>116,871</u>
Grand total	<u>¹125,031</u>	<u>¹139,135</u>	<u>117,224</u>	<u>132,886</u>

¹Revised. W Withheld to avoid disclosing company proprietary data; included with "Undistributed."

²Includes pyrite cinder.

³Included with synthetic black iron oxide to avoid disclosing company proprietary data.

⁴Includes other specialty oxides and mixtures of natural and synthetic iron oxides.

⁵Included with synthetic brown iron oxide to avoid disclosing company proprietary data.

⁶Data may not add to totals shown because of independent rounding.

TABLE 3
PRODUCERS OF IRON OXIDE PIGMENTS, REGENERATOR IRON OXIDES,
AND STEEL-PLANT WASTE IRON OXIDES IN THE UNITED STATES IN 1991

Producers	Plant location
Finished pigments:	
AST Co.	Granite City, IL.
American Minerals	Camden, NJ.
Blue Ridge Talc Co., Inc.	Henry, VA.
Columbian Chemicals Co.	St. Louis, MO, and Monmouth Junction, NJ.
DCS Color & Supply Co., Inc.	Milwaukee, WI.
George B. Smith Color Co.	Kirkland, IL.
Harcros Pigments Inc.	Emeryville, CA, East St. Louis, IL, Easton, PA.
Hilton-Davis Co.	Cincinnati, OH.
Hoover Color Corp.	Hiwassee, VA.
Mineral Pigments Corp.	Beltsville, MD.
Mobay Corp. Inorganic Chemicals Div.	New Martinsville, WV.
New Riverside Ochre Co., Inc.	Cartersville, GA.
Pea Ridge Iron Ore Co.	Sullivan, MO.
Prince Manufacturing Co.	Quincy, IL, and Bowmanstown, PA.
Solomon Grind-Chem Services Inc.	Springfield, IL.
Swansea Minerals Inc.	Tempe, AZ.
Crude pigments:	
Cleveland-Cliffs Iron Co., Mather Mine and Pioneer plant (closed July 31, 1979; shipping from stockpile.)	Negaunee, MI.
Hoover Color Corp.	Hiwassee, VA.
New Riverside Ochre Co., Inc.	Cartersville, GA.
Pea Ridge Iron Ore Co.	Sullivan, MO.
Swansea Minerals Inc.	Tempe, AZ.
Virginia Earth Pigments Co.	Hillsville, VA.
Regenerator and steel plant waste iron oxides:	
Armco Inc.	Ashland, KY.
Chesapeake Specialty Products	Baltimore, MD.
Gulf States Steel, Inc.	Gadsden, AL.
Perox ¹	Birmingham, AL, and Sharon, PA.
Petco Inc. ²	Lehi, UT.
Shance Chemical Corp.	Philadelphia, PA.
Weirton Steel Corp.	Weirton, WV.

¹Out of business; plants continued to produce under new owners and/or operators.

²Out of business; Geneva Steel adopted a new process.

TABLE 4
ESTIMATED IRON OXIDE PIGMENT CONSUMPTION, BY END USE, AS
A PERCENTAGE OF REPORTED SHIPMENTS

End use	All iron oxides		Natural iron oxides		Synthetic iron oxides	
	1990	1991	1990	1991	1990	1991
Coatings (industrial finishes, trade sales lacquers, paints, varnishes)	24	22	17	15	29	26
Construction materials (cement, mortar, preformed concrete, roofing granules)	32	29	24	20	39	35
Colorants for ceramics, glass, paper, plastics, rubber, textiles	17	18	20	18	14	19
Foundry sands	4	6	12	16	(¹)	—
Industrial chemicals (such as catalysts)	6	5	1	1	9	7
Ferrites	W	W	W	W	W	W
Animal feed and fertilizers	5	6	11	13	W	W
Other (including cosmetics, magnetic ink and toner, and polishing agents)	² 12	² 14	² 15	² 17	³ 9	³ 13
Total	100	100	100	100	100	100

W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Less than 1/2 unit.

²Includes ferrite iron oxide usage.

³Includes ferrites and animal feed and fertilizers iron oxide usage.

TABLE 5
U.S. EXPORTS OF IRON OXIDES AND HYDROXIDES, BY COUNTRY

Country	1990				1991			
	Pigment grade		Other grade		Pigment grade		Other grade	
	Quantity (metric tons)	Value (thousands)						
Algeria	—	—	12	\$37	—	—	23	\$4
Argentina	47	\$172	17	95	58	\$207	234	746
Australia	1,356	214	1,194	2,627	797	867	779	1,739
Austria	133	45	1,147	2,262	—	—	1,161	2,479
Bahamas	—	—	815	74	—	—	45	23
Barbados	—	—	17	27	—	—	—	—
Belgium	701	731	6,711	2,516	1,856	1,009	850	5,630
Bermuda	—	—	15	251	—	—	—	—
Bolivia	—	—	12	32	—	—	37	23
Brazil	126	764	197	626	115	722	560	910
Canada	873	1,398	134,549	23,389	574	921	110,391	23,251
Chile	—	—	138	111	2	3	15	37
China	32	120	24	618	—	—	237	1,235
Colombia	—	—	287	597	20	17	204	230
Costa Rica	—	—	79	84	2	4	84	50
Cyprus	—	—	20	31	—	—	—	—
Denmark	—	—	501	473	2	5	28	96
Dominican Republic	35	43	42	37	35	8	46	31
Ecuador	17	3	57	24	29	5	130	54
Egypt	—	—	—	—	—	—	20	78
El Salvador	—	—	12	14	—	—	83	35
Finland	33	50	10	13	—	—	1	11
France	160	424	550	1,009	207	229	413	1,077
Germany, Federal Republic of	232	281	10,926	12,249	3,076	2,982	6,097	9,193
Ghana	—	—	—	—	—	—	187	125
Greece	—	—	—	—	—	—	42	32
Guatemala	—	—	88	92	—	—	15	20
Hong Kong	1,696	5,418	184	597	1,457	5,405	274	367
India	158	455	394	1,547	203	816	425	1,392
Indonesia	136	161	220	173	232	319	366	207
Ireland	62	122	—	—	86	430	16	26
Israel	2	9	—	—	8	20	—	—
Italy	60	91	2,790	2,208	91	178	1,283	4,143
Jamaica	58	29	28	31	45	29	—	3
Japan	586	774	12,774	22,185	2,264	2,361	18,024	22,777
Jordan	—	—	148	176	—	—	—	—
Korea, Republic of	406	913	4,836	11,659	2,820	8,176	3,176	8,589
Kuwait	—	—	73	154	—	—	3	13
Macao	—	—	78	296	—	—	4	19
Malaysia	19	8	16	29	155	75	152	275
Mexico	229	418	7,138	7,836	173	302	5,632	7,564
Morocco	—	—	—	—	—	—	508	334
Netherlands	532	1,078	1,274	2,656	431	855	2,825	2,095
Netherlands Antilles	(?)	3	32	344	—	—	65	251

See footnotes at end of table

TABLE 5—Continued
U.S. EXPORTS OF IRON OXIDES AND HYDROXIDES, BY COUNTRY

Country	1990				1991			
	Pigment grade		Other grade		Pigment grade		Other grade	
	Quantity (metric tons)	Value (thousands)						
New Zealand	2	\$6	38	\$47	549	\$682	27	\$33
Nicaragua	—	—	—	—	—	—	15	5
Nigeria	—	—	131	164	—	—	18	4
Pakistan	—	—	—	—	16	32	256	306
Peru	—	—	(¹)	4	14	28	13	11
Philippines	299	384	152	193	405	496	49	86
Qatar	—	—	60	262	—	—	—	—
Saudi Arabia	5	9	509	583	7	29	394	969
Singapore	651	2,015	748	1,324	161	478	305	544
South Africa, Republic of	43	97	1,679	1,496	1,336	1,718	657	871
Spain	47	49	156	321	161	195.00	79	256
Sweden	—	—	239	144	20	21	88	403
Switzerland	11	41	872	301	—	—	473	527
Taiwan	46	59	1,226	1,559	361	376	2,433	4,096
Thailand	1,169	781	601	1,438	1,004	1,005	453	799
Trinidad	—	—	67	403	—	—	12	95
Tunisia	—	—	10	22	—	—	—	—
Turkey	14	23	—	—	—	—	10	168
United Kingdom	653	1,362	4,486	4,693	1,808	2,760	2,867	4,137
Venezuela	6	131	547	452	9	22	1,418	842
Yugoslavia	—	—	60	79	—	—	—	—
Zaire	—	—	215	161	—	—	—	—
Other	3	10	45	259	16	28	82	143
Total ³	9,535	18,694	199,470	111,081	20,606	33,813	164,084	109,463

¹Revised.

²Data was erroneously transposed in 1990 for Australia and Austria.

³Less than 1/2 unit.

⁴Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 6
U.S. IMPORTS FOR CONSUMPTION OF SELECTED IRON OXIDE PIGMENTS, BY TYPE

Type	1990		1991		Sources, 1991 ¹ (metric tons)
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	
Natural:					
Earth colors ²	1,301	943	301	797	Federal Republic of Germany 219; France 21; Spain 20; Canada 19; Japan 10; United Kingdom 7; Pakistan 5.
Micaceous	178	225	793	141	France 638; China 150; Netherlands 3; Australia 1; Japan 1.
Umber	400	125	2,135	638	Cyprus 2,038; Federal Republic of Germany 77; Spain 20.
Vandyke brown	76	66	58	49	Federal Republic of Germany 58.
Total¹	1,956	1,359	3,288	1,624	
Synthetic:					
Black	8,380	15,298	9,022	18,676	Canada 3,989; Japan 3,811; Federal Republic of Germany 980; China 184; Sweden 30; Mexico 17; Italy 10; Mauritius 1.
Red	11,127	7,124	12,182	8,289	Canada 4,735; Federal Republic of Germany 2,778; Mexico 1,029; China 1,014; Sweden 842; Spain 614; Japan 510; Brazil 422; United Kingdom 119; Italy 81; Belgium 17; India 20.
Yellow	11,492	10,803	8,915	8,737	Federal Republic of Germany 3,406; Canada 1,466; China 1,313; Mexico 1,020; Brazil 972; United Kingdom 555; Hungary 65; Japan 56; Spain 52; Australia 6; Switzerland 2; Denmark 2; Belgium 1.
Other ³	1,141	2,693	1,318	2,035	Federal Republic of Germany 824; China 168; Japan 110; Canada 52; United Kingdom 45; Sweden 28; Mexico 27; Poland 24; Italy 20; Australia 14; Spain 4; New Zealand 2; Belgium 1; Hong Kong 1.
Total¹	32,141	35,918	31,437	37,736	
Grand total¹	34,096	37,276	34,725	39,360	

¹Revised.

²Data may not add to totals shown because of independent rounding.

³Includes those earth colors not elsewhere specified or included.

⁴Includes synthetic brown oxides, transparent oxides, and magnetic and precursor oxides.

Source: Bureau of the Census.

TABLE 7
U.S. IMPORTS FOR CONSUMPTION OF IRON OXIDE AND IRON HYDROXIDE PIGMENTS, BY COUNTRY

Country	Natural				Synthetic			
	1990		1991		1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	—	—	1	\$5	50	\$74	20	\$26
Austria	90	\$93	—	—	—	—	—	—
Belgium	—	—	—	—	6	66	19	138
Brazil	—	—	—	—	1,216	971	1,394	1,201
Canada	1	2	19	33	11,258	5,035	10,242	3,942
China	17	9	150	75	1,416	716	2,679	1,322
Colombia	—	—	—	—	12	10	—	—
Cyprus	1,372	305	2,038	559	—	—	—	—
Finland	—	—	—	—	1	13	(¹)	9
France	—	—	659	79	—	—	—	—
Germany, Federal Republic of	385	820	354	822	8,530	9,711	7,988	9,266
Hong Kong	—	—	—	—	15	18	1	2
Hungary	—	—	—	—	16	27	65	111
India	—	—	—	—	31	129	20	10
Italy	—	—	—	—	15	18	111	68
Japan	3	85	11	21	3,171	13,530	4,487	18,537
Malaysia	—	—	(¹)	1	—	—	—	—
Mexico	—	—	—	—	3,177	3,009	2,093	1,750
Netherlands	8	11	3	4	117	44	—	—
New Zealand	—	—	—	—	135	256	2	35
Pakistan	—	—	5	2	—	—	—	—
Poland	—	—	—	—	—	—	24	74
Spain	78	25	40	18	938	710	670	305
Sweden	—	—	—	—	800	159	900	213
Switzerland	—	—	—	—	1	11	2	24
United Kingdom	1	7	7	4	1,201	1,335	719	699
Venezuela	—	—	—	—	33	54	—	—
Other	—	—	—	—	3	34	—	—
Total²	1,956	1,359	3,288	1,624	32,141	35,918	31,437	37,736

¹Revised.

²Less than 1/2 unit.

³Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 8
NATURAL IRON OXIDE PIGMENTS: WORLD MINE PRODUCTION,
BY COUNTRY¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991 ³
Argentina	1,022	815	578	*600	600
Austria	10,807	9,938	10,924	*9,936	10,000
Brazil	5,803	5,223	*5,500	*5,500	5,500
Canada	¹ (?)	¹ (?)	¹ (?)	¹ (?)	—
Chile	8,145	8,542	23,653	*15,557	16,000
Cyprus	12,500	10,060	8,534	*7,700	8,000
France ⁴	15,000	15,000	15,000	15,000	15,000
Germany: Western states ⁴	10,003	8,143	*7,596	*6,218	6,000
India	145,245	151,781	173,366	*180,000	125,000
Iran ⁵	4,300	4,300	4,300	*4,500	4,500
Italy ⁶	850	850	850	850	700
Pakistan (ocher)	1,792	1,040	2,394	*1,382	1,400
Paraguay ⁶	285	250	250	250	250
South Africa, Republic of	768	2,070	1,327	*2,903	⁵ 908
Spain: ⁶					
Ocher	10,500	10,500	10,500	10,500	8,200
Red iron oxide	20,500	20,500	20,500	20,500	20,000
United States	31,816	30,747	36,661	32,421	⁵ 34,083
Yugoslavia	1,061	444	853	1,212	800
Zimbabwe	*200	363	287	*416	400

¹Estimated. ²Revised.

³Table includes data available through Apr. 28, 1992.

⁴In addition to the countries listed, a considerable number of others undoubtedly produce iron oxide pigments, but output is not reported, and no basis is available for formulating estimates of output levels. Such countries include, but are not limited to, China and the U.S.S.R. Because unreported output is probably substantial, this table is not summed to provide a world total.

⁵Revised to zero. Production of crude iron oxide pigments in Canada cannot be verified. Production of iron oxides in Canada is limited to synthetic pigments and regenerator oxide.

⁶Includes Vandyke brown.

⁷Reported figure.

IRON AND STEEL

By Gerald W. Houck

Mr. Houck, a physical scientist with 35 years of industry and U.S. Bureau of Mines experience, is the commodity specialist for iron and steel. International data tables were prepared by Harold Willis, international data coordinator, and Ted Spittal, Orkand Corp. Ferroalloys survey data were prepared by Jo-Ann Sterling and Robin Johnson, mineral data assistants.

Iron and steel are vital to the United States for both national security and economic well-being. They are the basic metals of an industrial society. Although there are many acceptable substitutes for many of their uses, in the short term, there are no practical substitutes on a large scale because of the cost and lack of availability of alternative materials. Ferroalloys are alloys of iron that contain a sufficient amount of one or more other chemical elements to be useful as an agent to introduce these other elements into a molten metal, usually steel.

In prior years, the U.S. Bureau of Mines has published a separate annual Minerals Yearbook chapter covering ferroalloys. This year, data tables on ferroalloys production and consumption are contained in this chapter. The reader is referred to the Yearbook chapters dealing with specific elements, especially those for chromium, manganese, and silicon, for analysis and detail with respect to the ferroalloys industry.

This was a poor year for the U.S. steel industry, as production and shipments of steel products declined along with the recessionary economy. Production of raw steel in the United States dropped more than 11% to 79.7 million metric tons, from 89.7 million produced in 1990. Net shipments of steel mill products by U.S. companies dropped about 7%, to 71.5 million tons, from 77.1 million tons in 1990.

Imports of steel mill products declined about 8%, to 14.3 million tons, from 15.6 million tons in 1990. Imports captured 17.8% of the apparent consumption of mill products, up from

17.5% in 1990. Imports of fabricated steel products, such as fasteners, wire, and fabricated structural steel, totaled 1.7 million tons, representing another 2% of the U.S. steel market. (See tables 1 and 2.)

Exports of steel mill products increased to 5.8 million tons, from 3.9 million tons in 1990. This was the fifth consecutive year of increased steel mill product exports by U.S. companies and was the second highest year for steel mill product exports since World War II.

Prices of steel mill products declined in 1991. The Bureau of Labor Statistics' Producer Price Index for steel mill products declined 2.3% to 109.5 (1982 base=100.0).

The combination of lower volume and lower selling prices resulted in continued financial losses for the U.S. steel industry. The American Iron and Steel Institute, reporting on the aggregated financial results of companies that produced about 64% of the Nation's raw steel in 1991, announced that 1991 losses were \$2,072 million on steel sales of \$27,270 million. These companies have reported cumulative losses of \$11,540 million over the 10-year period 1982-91.

Worldwide production of raw steel in 1991 was 733.7 million tons, down 5% from that of 1990. Production in Eastern Europe and the former U.S.S.R. fell dramatically--more than 18% in 1991 alone. In China and other developing nations of Asia, Africa, and the Middle East, however, growth continued at a vigorous pace, partially offsetting the declines in the United States and the Eastern bloc. Production in Western

Europe and Japan was about the same as that in 1990.

Consistent with international usage, the U.S. Bureau of Mines is reporting all data on iron and steel in metric units, unless otherwise noted.

DOMESTIC DATA COVERAGE

Data regarding U.S. production of iron and steel and shipments of steel mill products are those reported by the American Iron and Steel Institute. These data can be regarded as representing 100% of the raw steel producers in the United States.

BACKGROUND

Definitions, Grades, and Specifications

Iron is the most useful and most abundant, as well as the cheapest of the metallic elements. It is also the most versatile and most widely studied and understood. Its many uses are based on the properties of its alloys; iron is never used by itself. Some of its useful alloys include the word "iron"; viz, pig iron, wrought iron, gray iron, malleable iron, ductile iron; others are known as "steel." The term "steel" was originally applied to an alloy of iron that would become very hard if cooled rapidly from a high temperature. Early steelmakers did not know that a carbon content from about 0.3% to about 1% is required for producing these properties, but by trial and error they developed empirical methods to produce metals of the proper carbon content.

Today, "iron" refers to alloys that contain too much carbon to be formable by forging or rolling. "Pig iron" contains about 4.5% carbon and is useful only for steelmaking or for remelting into cast-iron products. Gray iron, malleable iron, and ductile iron are categories of cast iron and are produced by the foundry industry.

In modern terminology, "steel" refers to an alloy of iron that is malleable at some temperature containing manganese, carbon, and often other alloying elements. Steel containing only carbon and manganese is called "carbon steel"; steel containing metallic elements such as nickel, chromium, or molybdenum is termed "alloy steel"; and steel containing sufficient chromium to confer a superior corrosion resistance is called "stainless steel." Hundreds of individual alloy specifications have been developed to produce combinations of strength, ductility, hardness, toughness, magnetic permeability, and corrosion resistance to meet the needs of modern consumers. These alloy specifications are called "grades."

The malleability property of steel allows it to be produced by rolling or forging into a variety of product forms. Examples of forms include structural shapes (such as beams and angles), rails (such as railroad rails), round bars, wire, various types of pipe and tubular products, and flat-rolled products. In every case, the product is produced on specialized equipment in a range of sizes to suit intended applications.

For some products, metallic or nonmetallic coatings are applied to the product by the steel producer. Additionally, various thermal treatments may be used to provide the customer's required properties.

"Steel mill products" refers to products produced by a steel mill, either by forging or rolling, in the form normally delivered for fabrication or use. Some companies purchase semifinished steel mill products from other steel companies and use these semifinished products to produce steel mill products. To avoid double counting of steel mill product shipments under these circumstances,

steel mills identify any shipments of steel mill products to other companies that are reporters of steel mill product shipments. The accumulated shipments of all companies, less the shipments to other reporting companies, are identified as "net" shipments.

Regarding the reporting of imports and exports, "fabricated steel products" are products produced from steel mill products, but not including products that incorporate steel products along with other materials. Examples of fabricated steel products are fabricated structural steel and steel fasteners. "Other iron and steel products" refers to products that are not produced from steel mill products. Examples of other iron and steel products include iron or steel castings and direct-reduced iron.

Industry Structure

Integrated Steel Producers.—Integrated steel producers are those that smelt iron ores to crude liquid iron in blast furnaces and refine the iron, with some scrap, in basic oxygen furnaces, producing liquid steel. The liquid steel is mostly cast into semifinished products in continuous casting machines, although 24% of U.S. production in 1991 was cast in ingot form and subsequently rolled into semifinished form. The integrated steel industry in the United States in 1991 consisted of 16 companies, operating ironmaking and steelmaking facilities at 24 locations. Several of these companies also operated nonintegrated plants and/or other steelmaking facilities at the same locations.

The product mix of the integrated producers consists predominantly of flat products: sheet and strip, some of which is galvanized or tinplated. Some integrated producers made structural shapes and bar products as well, but, for the most part, these products are produced by nonintegrated mills.

Nonintegrated Steel Producers.—Nonintegrated steel producers melt raw materials, primarily scrap, in electric furnaces. Broadly

speaking, there are two subcategories of nonintegrated mills: minimills and specialty mills. "Minimills" is a term used to describe steel producers that utilize modern technology in a plant built to produce a limited product line with maximum efficiency. These plants always incorporate electric melting of low-cost raw materials, continuous casting, and a hot-rolling mill, often closely coupled to the casting operation. It was once accepted that minimills produced only simple bar products such as reinforcing bars, wire rods, and small structural shapes. Today, however, minimills have become dominant in all long products, including special quality bars and large structural shapes. One company has successfully applied the minimill concept to the production of flat-rolled steel with the successful operation of a thin-slab (50-millimeter) casting machine, closely coupled to a hot-strip mill, producing commercial quality hot bands. This plant produced 1 million tons and operated at a profit during 1991, according to the company. Several companies operate multiple minimills with cumulative steelmaking capability greater than that of the smaller integrated mills.

The second category of nonintegrated mills, specialty mills, is less well defined. Specialty mills definitely include the producers of stainless steel, alloy electrical steel, tool steel, and high-temperature alloys. In addition, this category includes producers of forging ingots and a variety of steel plants that, while not producing a large quantity of steel, are a significant part of what is called "the steel industry."

Overall, the nonintegrated sector of the industry consisted of 68 companies, with 96 raw steelmaking locations.

Substitutes

Iron, as steel or cast iron, is the most widely used metal in the world because of its high strength-to-cost ratio. In applications where strength is not the major requirement, iron competes with less expensive nonmetallic materials or more expensive materials having some

property advantage. Where weight reduction is required, aluminum, plastics, and occasionally magnesium or titanium may be substituted; motor vehicles and airplanes are obvious examples. In construction, concrete, usually reinforced with steel, and wood are frequently substituted for steel. In packaging, steel cans, pails, and household goods were largely replaced with aluminum, glass, plastics, and paper, but drums and other containers used for more severe applications are almost invariably made of steel.

ANNUAL REVIEW

Legislation and Government Programs

Since October 1, 1984, the import of steel products into the U.S. has been limited by a program of "Voluntary Restraint Agreements (VRA's)," which were negotiated following an investigation conducted by the U.S. International Trade Commission in which imports of certain steel products were found to be a substantial cause of serious injury, or threat thereof, to certain domestic industries. The President determined that imposing countervailing duties under the Trade Act of 1974 was not in the national economic interest and directed the U.S. Trade Representative to negotiate VRA's with countries whose exports to the United States had increased significantly in previous years due to an unfair surge in imports.

Agreements were negotiated with the European Community and 16 individual nations. Although the structure of the agreements varied from one country to another, each involved an agreement by the foreign Government to limit exports of certain steel products to the United States. To bring the agreements into effect, U.S. steel producers withdrew pending unfair trade petitions, and the U.S. Government suspended antidumping and countervailing duties that were in effect on the products covered by the agreements. The VRA's covered a 5-year period ending September 30, 1989.

In July 1989, the President announced a "Steel Trade Liberalization Program"

extending the VRA program for 2 1/2 years, to terminate March 31, 1992. Negotiations resulted in new agreements with the European Community and the 16 other countries.

During 1991, negotiations were conducted in an effort to reach a "Multilateral Steel Agreement" among the major steel trading nations. The proposed agreement would have established international disciplines on government subsidies. It would have defined some forms of government support, such as research and development grants or assistance for environmental protection purposes, as permissible, and accordingly, not subject to national countervailing duty laws. The agreement also would have phased out tariffs and prohibited a number of measures, such as quotas, VRA's, and special licensing provisions, that are designed to restrict or regulate trade in steel products. Agreement on the Multilateral Steel Agreement was not reached before the expiration of the VRA's on March 31, 1992.

As a result of the expiration of the VRA's and the failure to reach agreement on the Multilateral Steel Agreement as of mid-1992, there are no special trade provisions now in effect for steel; it is subject to the same agreements, including the General Agreement on Tariffs and Trade, as are other products.

Production

This was a poor year for the U.S. steel industry, as production and shipments of steel products declined along with the recessionary economy. Production of raw steel in the United States dropped more than 11% to 79.7 million tons from 89.7 million tons produced in 1990. Net shipments of steel mill products by U.S. companies dropped about 7% to 71.5 million tons from 77.1 million tons in 1990. The drop in production was greater than the drop in shipments because the steel companies trimmed inventories that had accumulated during the prior year. (See tables 3, 4, and 5.)

Electric arc furnace steelmaking was utilized for 38.4% of total steelmaking in 1991. This is the highest share ever for production for electric arc furnace steelmaking in the United States.

Open-hearth steelmaking dropped to 1.6% of the total. During 1991, both of the only operating open-hearth steelmaking shops in the United States were permanently shut down. One of the two, at Geneva Steel Co., Provo, UT, was replaced by a basic oxygen steelmaking plant. The other open-hearth shop, at the U.S. Steel Group (USX Corp.) plant near Philadelphia, PA, was shut down, along with the blast furnace iron-producing facility at the same site, as U.S. Steel Group apparently plans to supply steel produced at other locations to the finishing facilities located there.

The trend toward the use of continuous casting continued. The share of raw steel produced by continuous casting was 75.8%, up from its previous high of 67.4% in 1990. New continuous casting equipment was under construction at yearend at several locations, ensuring that the continuous casting ratio will continue to increase.

Consumption and Uses

Shipments of steel products by U.S. companies were down 7.2% to 71.5 million tons, but export shipments were up 80%. Shipments to domestic customers were down 11%. Shipments for some applications were down much more than that, as the recession hit hard in the industrial sectors of the economy; shipments for oil and gas drilling, mining, quarrying, and lumbering were down 26% from the 1990 level, and shipments for industrial and agricultural machinery, equipment, and tools were down 22%. Uses that were less severely impacted were automotive, which was down 10%, and containers, packaging, and shipping materials, which was down only 5%. (See table 6.)

Markets and Prices

Prices for steel mill products were under severe pressure during the entire

year. The Bureau of Labor Statistics' Producer Price Index for steel mill products was down by 2.4% at 109.5 (1982 base=100.0.) Numerous efforts by steel companies to increase their prices were reported, but vigorous competition prevented prices from being increased.

Foreign Trade

The U.S. steel companies increased their foreign sales of steel mill products. Exports of steel mill products increased to 5.8 million tons. This is the highest annual level of exports since 1970 and the second highest level since World War II. Canada was the nation receiving the largest amount of exported steel, 1.5 million tons, with Mexico in second place, receiving 1.2 million tons. Increases in exports to Mexico, Korea, and Japan represented most of the year-to-year increase in exports over 1990. (See tables 7 and 8.)

Imports of steel mill products declined about 8% from those of 1990. VRA'S were in effect during the entire year, but imports were, in the main, less than the restraint levels would have allowed. The combination of a weak dollar, slack demand, and vigorous competition apparently kept import allowances from being filled. The European Community, Canada, and Japan were major sources for steel mill product imports. Brazil and Korea were also major importers, with much of the steel from these countries being imported in semifinished form for conversion in the United States into other steel mill products. (See tables 9, 10, and 11.)

World Review

World production of pig iron and direct-reduced iron in 1991 totaled 528.5 million tons, down 4% from that of 1990. The collapse of economies in Eastern Europe and the former U.S.S.R., along with the recession in the United States, accounted for the decrease.

Direct-Reduced Iron.—Direct-reduced iron has become a significant part of world production. While pig iron production dropped, production of direct-reduced iron soared to almost 20 million tons in 1991, with an 8% increase in 1991 and 58% over the past 5 years. Direct reduction of iron ore has proved to be a cost effective way for developing countries, especially those with an abundance of natural gas, to encourage economic growth. As a result, in the Middle East, Southeast Asia, Mexico, and Venezuela, production of direct-reduced iron is on the increase.

As of November 1991, world capacity for direct-reduced-iron production was estimated to be 28 million tons, with an additional 11.5 million tons under construction. Developments in India and Iran deserve special mention. The Government of India is encouraging the development of direct-reduced-iron facilities to slow the high rate of scrap imports. Since 1989, four direct-reduced iron plants, with a combined capacity of 1.4 million tons, have been started up, bringing India's total annual capacity to 1.7 million tons. An additional 4 million tons of capacity is under construction, with completion planned from 1992 through 1994.

Iran's program to develop direct-reduced-iron facilities was interrupted by its war with Iraq. With that conflict over, construction of these facilities has been resumed. About 0.8 million tons of capacity was started up in 1990 and 1991; an additional 4.3 million tons is scheduled for 1992-94, which would bring Iran's total capacity for direct-reduced iron to 5.8 million tons.

Other nations where direct reduction facilities are under construction are Saudi Arabia (0.65 million tons scheduled for 1992), Malaysia (1.2 million tons, 1993) and Indonesia (1.35 million tons, 1993.) (See tables 12 and 13.)

Steel.—World production of steel was 733.7 million tons, down 5% from that of 1990. Declines in the United States, Eastern Europe, and the former U.S.S.R. were partially offset by continued strong

growth in China, Korea, and in the other nations of Southeast Asia and the Middle East. (See tables 14 and 15.)

OUTLOOK

The outlook for 1992 is for further declines in pig iron and steel production in the Eastern European nations and the former Soviet Republics. Strong growth will continue in China and the Far East.

In the United States, recovery from the depressed operations of 1991 is apparent, but the growth is not robust. Vigorous world competition will limit the ability of U.S. companies to maintain their record-breaking level of export sales.

The expiration of the VRA's on March 31, 1992, has increased the uncertainty about the future of imported steel. On June 30, 1992, a group of 12 domestic steel companies filed complaints alleging dumping and/or illegal subsidization against importers of flat-rolled sheet and strip products from 20 nations, including all the major steel importing nations. These pending petitions are currently causing even greater uncertainty in the steel marketplace. If the U.S. International Trade Commission finds that imports are a cause of "injury" to the domestic steel industry and if the Department of Commerce supports the allegations of dumping and subsidization, countervailing duties will be applied. (See tables 16 through 25.)

OTHER SOURCES OF INFORMATION

American Metal Market, daily.
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HYL, the Iron & Steel Technology Division of Hylsa, S.A. de C.V. HYL Report.
Making, Shaping and Treating of Steel, Association of Iron and Steel Engineers, Pittsburgh, PA.
Metal Bulletin, biweekly.

Midrex Corporation. Direct from Midrex, quarterly.
 Steel Manufacturers Association, Washington, DC.
 Steel Statistical Yearbook, International Iron and Steel Institute, Brussels, Belgium.
 Steel Times International.

TABLE 1
 SALIENT IRON AND STEEL STATISTICS

(Thousand metric tons)

	1987	1988	1989	1990	1991
United States:					
Pig iron:					
Production ¹	43,824	50,571	50,687	49,668	44,123
Exports	45	65	11	14	15
Imports for consumption	322	*635	443	347	434
Direct-reduced iron:					
Production	210	290	291	390	410
Exports	15	17	23	63	22
Imports for consumption	56	176	226	385	423
Raw steel production:²					
Carbon steel	70,739	78,764	78,227	78,553	70,651
Stainless steel	1,840	1,995	1,747	1,848	1,704
All other alloy steel	8,298	9,890	8,878	9,325	7,384
Total ³	80,876	90,650	88,852	89,726	79,738
Steel mill products:					
Net shipments	69,539	76,058	76,294	77,093	71,528
Exports ⁴	1,024	1,877	4,153	3,904	5,757
Imports ⁴	18,519	18,952	15,713	*15,575	14,280
Producer price index for steel mill products ⁵	102.3	110.7	114.5	112.1	109.5
World production:⁶					
Pig iron	*508,895	*539,602	*546,306	*532,607	*508,730
Direct-reduced iron	*13,825	*14,286	*16,641	*18,366	*19,755
Raw steel	*734,319	*779,782	*786,219	*770,638	*733,673

*Estimated. †Revised.

¹American Iron and Steel Institute (AISI).

²Raw steel is defined by AISI as steel in the first solid state after melting, suitable for rolling.

³Data may not add to totals shown because of independent rounding.

⁴Source: Bureau of the Census.

⁵Source: Bureau of Labor Statistics. (1982=100.0)

⁶Sources: U.S. Bureau of Mines and International Iron and Steel Institute.

TABLE 2
EFFICIENCY TRENDS: U.S. STEEL PRODUCTION

Year	Raw steel		
	Capability ¹ (thousand metric tons)	Capability utilization (percent)	Continuous cast (percent)
1982	139,700	48.4	29.0
1983	136,600	56.2	32.1
1984	122,700	68.4	39.6
1985	121,200	66.1	44.4
1986	115,200	63.8	55.2
1987	101,800	79.5	59.8
1988	101,600	89.2	61.3
1989	105,100	84.5	64.8
1990	105,900	84.7	67.4
1991	106,700	74.7	75.8

¹Revised.

¹Raw steel production capability is defined by American Iron and Steel Institute as the tonnage capability to produce raw steel for a sustained full order book.

Source: American Iron and Steel Institute.

TABLE 3
**MATERIALS CONSUMED IN BLAST FURNACES AND PIG IRON
PRODUCED**

(Thousand metric tons)

Material	1987	1988	1989	1990	1991
Iron oxides:¹					
Ores	2,696	5,155	3,211	2,479	1,918
Pellets	49,500	61,025	61,659	60,512	51,290
Sinter ²	14,420	15,497	13,664	12,226	10,299
Total ³	66,616	81,676	78,533	75,217	63,507
Scrap ⁴	3,074	2,732	3,006	2,527	2,142
Coke	21,801	26,709	26,467	24,946	22,496
Pig iron produced	43,824	50,571	50,687	49,668	44,123

¹Revised.

¹American Iron and Steel Institute.

²Includes sintered ore and pellet fines, dust, mill scale, and other revert iron-bearing materials; also some nodules.

³Data may not add to totals shown because of independent rounding.

⁴Mainly briquetted turnings and borings, shredded scrap, etc.; scrap produced at blast furnaces and remelted not included.

TABLE 4
U.S. STEEL PRODUCTION, BY TYPE OF STEELMAKING FURNACE

Year	Basic oxygen		Basic open hearth		Basic electric arc		Total (thousand metric tons) ¹
	Quantity (thousand metric tons)	Percent	Quantity (thousand metric tons)	Percent	Quantity (thousand metric tons)	Percent	
1987	47,624	58.9	2,419	3.0	30,834	38.1	80,876
1988	52,580	58.0	4,643	5.1	² 33,426	36.9	90,650
1989	52,932	59.6	4,030	4.5	31,891	35.9	88,852
1990	53,044	59.1	3,172	3.5	² 33,510	37.3	89,726
1991	47,821	60.0	1,277	1.6	30,639	38.4	79,738

¹Data may not add to totals shown because of independent rounding.

Source: American Iron and Steel Institute.

TABLE 5
U.S. CONSUMPTION OF SCRAP AND PIG IRON IN STEEL PRODUCTION, BY TYPE OF STEELMAKING FURNACE¹

(Thousand metric tons)

Year	Basic oxygen		Basic open hearth		Basic electric arc		Total	
	Scrap	Pig iron	Scrap	Pig iron	Scrap ²	Pig iron	Scrap	Pig iron
1987	² 14,236	² 42,403	¹ 1,031	(³)	33,137	1,457	² 48,404	² 43,860
1988	² 16,168	² 47,198	887	3,500	35,775	225	² 52,830	² 50,923
1989	² 15,161	² 49,379	859	1,582	34,076	313	² 50,096	² 51,274
1990	² 14,346	² 47,307	1,731	2,072	35,646	7	² 51,723	² 49,386
1991	13,320	43,761	548	997	32,458	6	46,326	44,764

²Estimated. ³Revised.

¹Pig iron mainly as liquid in basic oxygen and open-hearth furnaces.

²Included with electric arc.

Source: U.S. Bureau of Mines.

TABLE 6
DISTRIBUTION OF SHIPMENTS OF STEEL MILL PRODUCTS, BY PERCENT

	1987	1988	1989	1990	1991
Net shipments thousand metric tons	73,161	80,187	76,294	77,093	71,528
Shipments by steel type:					
Carbon steel	89.0	92.7	93.3	92.7	93.2
Alloy steel	9.0	5.3	4.9	5.5	5.0
Stainless steel	2.0	2.0	1.7	1.8	1.8
Steel mill products:					
Ingot, blooms, billets, and slabs	2.11	2.30	2.48	2.33	3.23
Wire rods	5.01	4.83	4.94	5.09	5.54
Structural shapes-heavy	6.31	5.80	5.93	6.67	6.65
Steel piling	.37	.42	.44	.50	.55
Plates—cut lengths	5.28	6.02	6.05	6.04	5.42
Plates—in coils	(¹)	2.72	2.73	3.31	3.38
Rails—standard	.46	.55	.54	.48	.48
Rails—other	.02	.04	.01	.01	.02
Railroad accessories	.19	.14	.11	.12	.11
Bars—hot-rolled	7.89	7.71	7.49	7.83	6.89
Bars—light-shaped	1.55	1.64	1.57	1.44	1.47
Bars—reinforcing	6.42	6.07	5.96	6.24	6.16
Bars—cold-finished	1.78	1.79	1.75	1.75	1.70
Tool steel	.08	.08	.07	.07	.06
Pipe and tubing—standard pipe	1.26	1.48	1.39	1.39	1.23
Pipe and tubing—oil country goods	1.20	1.35	1.43	1.43	1.37
Pipe and tubing—line pipe	.81	.96	1.32	1.32	1.82
Pipe and tubing—mechanical tubing	1.00	1.07	.96	1.02	.94
Pipe and tubing—pressure tubing	.09	.07	.06	.06	.06
Pipe and tubing—stainless	.05	.07	.06	.05	.04
Pipe and tubing—structural	.24	.21	.14	.16	.19
Pipe for piling	NA	.09	.04	.04	.03
Wire	1.44	1.28	1.19	1.08	1.10
Tin mill products—blackplate	.27	.34	.37	.32	.32
Tin mill products—tinplate	3.61	3.35	3.32	3.26	3.49
Tin mill products—tin-free steel	1.22	1.07	1.11	1.07	1.22
Tin mill products—tin coated sheets	.10	.10	.10	.09	.09
Sheets—hot-rolled	17.02	15.02	15.34	15.75	16.69
Sheets—cold-rolled	18.08	16.54	16.47	15.53	14.63
Sheets and strip—hot-dip galvanized	9.99	9.68	10.16	9.27	8.76
Sheets and strip—electroalvanized	1.87	2.55	2.56	2.43	2.66
Sheets, and strip—other metallic coated	1.60	1.51	1.64	1.48	1.45
Sheets and strip—electrical	.61	.62	.58	.57	.58
Strip—hot-rolled	.86	1.43	1.29	.81	.68
Strip—cold-rolled	1.21	1.12	1.03	.96	.96
Total steel mill products	100.00	100.00	100.00	100.00	100.00
Shipments by markets:					
Service centers and distributors	25.9	25.1	24.7	24.8	24.7
Construction	14.4	14.4	13.7	14.3	14.5
Automotive	14.8	15.0	14.0	13.1	12.7

See footnotes at end of table.

TABLE 6—Continued
DISTRIBUTION OF SHIPMENTS OF STEEL MILL PRODUCTS, BY PERCENT

	1987	1988	1989	1990	1991
Shipments by markets—Continued:					
Machinery	9.7	9.6	2.6	2.8	8.0
Containers	5.7	5.3	5.3	5.3	5.4
All others	29.5	30.6	39.1	39.7	34.7

NA Not available.

¹Included in "sheets—hot-rolled."

Source: American Iron and Steel Institute.

TABLE 7
U.S. IMPORTS AND EXPORTS OF STEEL MILL PRODUCTS, BY COUNTRY

(Thousand metric tons)

Country	1987		1988		1989		1990		1991	
	Imports	Exports								
Argentina	300	5	484	43	191	40	171	19	177	21
Brazil	1,001	15	1,242	6	1,252	26	1,335	14	1,281	14
Canada	3,329	376	2,878	448	2,699	579	2,606	1,580	2,657	1,520
China	45	—	29	100	16	373	13	7	12	91
European Community	5,263	112	5,648	230	5,061	331	4,949	269	4,240	226
Japan	3,920	12	3,892	192	3,314	524	2,826	411	2,558	604
Korea, Republic of	1,176	22	1,186	41	901	658	1,205	279	1,286	790
Mexico	442	179	427	312	399	429	585	591	454	1,159
Taiwan	230	37	213	61	128	127	174	17	117	396
Taiwan	230	37	213	61	128	127	174	17	117	396
Venezuela	154	7	152	9	142	16	184	28	84	102
Venezuela	154	7	152	9	142	16	184	28	84	102
All others	2,659	260	2,800	435	1,609	1,050	1,528	688	1,413	835
Total ¹	18,519	1,024	18,952	1,877	15,713	4,153	15,575	3,904	14,280	5,757

¹Data may not add to totals shown because of independent rounding.

Source: American Iron and Steel Institute.

TABLE 8
U.S. EXPORTS OF IRON AND STEEL PRODUCTS

(Thousand metric tons)

	1990	1991
Steel mill products:		
Ingots, blooms, billets, and slabs	474	634
Wire rods	97	151
Structural shapes-heavy	279	368
Steel piling	6	9
Plates—cut lengths	152	251
Plates—in coils	264	412
Rails—standard	53	20
Rails—other	5	9
Railroad accessories	4	8
Bars—hot-rolled	195	209
Bars—light-shaped	48	45
Bars—concrete reinforcing	108	213
Bars—cold-finished	49	51
Tool steel	4	9
Pipe and tubing—standard pipe	29	34
Pipe and tubing—oil country goods	177	329
Pipe and tubing—line pipe	67	147
Pipe and tubing—mechanical tubing	6	9
Pipe and tubing—stainless	12	14
Pipe and tubing—nonclassified	108	126
Pipe and tubing—structural	22	19
Pipe for piling	5	6
Wire	64	81
Tin mill products—blackplate	2	4
Tin mill products—tinplate	134	137
Tin mill products—tin-free steel	23	34
Sheets—hot-rolled	622	1,450
Sheets—cold-rolled	325	367
Sheets and strip—hot-dip galvanized	181	163
Sheets and strip—electrogalvanized	79	112
Sheets and strip—other metallic coated	94	91
Sheets and strip—electrical	43	76
Strip—hot-rolled	65	66
Strip—cold-rolled	107	103
Total steel mill products¹	3,904	5,757
Fabricated steel products:		
Structural shapes—fabricated	194	248
Rails—used	42	41
Railroad products	11	20
Wire rope	4	4
Wire—stranded products	13	17
Wire—other products	9	14
Springs	27	26
Nails and staples	11	13
Fasteners	164	153
Chains and parts	21	21

See footnotes at end of table.

TABLE 8—Continued
U.S. EXPORTS OF IRON AND STEEL PRODUCTS

(Thousand metric tons)

	1990	1991
Fabricated steel products—Continued:		
Grinding balls	41	45
Pipe and tube fittings	16	16
Other	25	27
Total fabricated steel products	578	645
Total all steel products¹	4,481	6,402
Cast iron and steel products:²		
Cast steel pipe fittings	80	72
Cast iron pipe and fittings	11	13
Cast steel rolls	11	11
Cast grinding balls	17	14
Granules—shot and grit	26	26
Other castings	27	29
Total cast iron and steel products	172	165

¹Revised.

²Data may not add to totals shown because of independent rounding.

³In 1990 category was listed as "Iron products."

Source: American Iron and Steel Institute.

TABLE 9
U.S. IMPORTS OF PIG IRON, BY COUNTRY

(Metric tons)

Country	1987	1988	1989	1990	1991
Brazil	107,716	450,795	310,196	219,041	327,603
Canada	190,416	131,874	120,597	124,938	84,254
South Africa, Republic of	—	—	—	—	21,243
Other	23,658	52,416	12,072	3,233	1,219
Total¹	321,789	635,085	442,865	347,212	434,318

¹Revised.

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 10
IMPORTS OF MAJOR IRON AND STEEL PRODUCTS

(Thousand metric tons)

	1990	1991
Steel mill products:		
Ingots, blooms, billets and slabs	2,144	1,954
Wire rods	871	750
Structural shapes-heavy	750	417
Steel piling	81	57
Plates—cut lengths	870	727
Plates—in coils	557	444
Rails and railroad accessories	120	141
Bars—hot-rolled	614	603
Bars—light-shaped	84	65
Bars—reinforcing	134	97
Bars—cold-finished	147	138
Tool steel	53	60
Pipe and tubing—standard pipe	863	759
Pipe and tubing—oil country goods	352	374
Pipe and tubing—line pipe	631	910
Pipe and tubing—mechanical tubing	169	154
Pipe and tubing—pressure tubing	35	33
Pipe and tubing—stainless	43	44
Pipe and tubing—nonclassified	9	6
Pipe and tubing—structural	250	190
Pipe for piling	4	11
Wire	392	355
Tin mill products—blackplate	133	117
Tin mill products—tinplate	284	282
Tin mill products—tin-free steel	103	104
Sheets—hot rolled	2,070	1,924
Sheets—cold rolled	1,859	1,712
Sheets and strip—hot-dip galvanized	1,146	1,154
Sheets and strip—electrogalvanized	350	224
Sheets and strip—other metallic coated	175	172
Sheets and strip—electrical	69	74
Strip—hot-rolled	88	96
Strip—cold-rolled	126	128
Total steel mill products¹	15,575	14,280
Fabricated steel products:		
Structural shapes-fabricated	87	69
Rails—used	154	93
Railroad products	40	38
Wire rope	85	79
Wire—stranded products	152	99
Wire—other products	77	60
Springs	213	190
Nails and staples	341	263
Fasteners	655	619

See footnotes at end of table.

TABLE 10—Continued
IMPORTS OF MAJOR IRON AND STEEL PRODUCTS

(Thousand metric tons)

	1990	1991
Fabricated steel products—Continued:		
Chains and parts	67	60
Pipe and tube fittings	126	118
Other	20	22
Total fabricated steel products¹	2,016	1,709
Total all steel products	17,591	15,989
Cast iron and steel products:²		
Cast steel pipe fittings	20	16
Cast iron pipe and fittings	27	23
Other products	168	148
Total cast products	215	187

¹Revised.

²Data may not add to totals shown because of independent rounding.

³In 1990 category was listed as "Iron products."

Source: American Iron and Steel Institute.

TABLE 11
U.S. IMPORTS OF STAINLESS STEEL¹

(Metric tons)

Product	1987	1988	1989	1990	1991
Semifinished	*51,460	56,615	56,355	*55,177	44,418
Plate	*10,086	*14,376	*16,069	*18,734	19,503
Sheet and strip	*117,294	107,578	127,477	140,017	145,766
Bars and shapes	34,465	*36,944	39,387	40,393	47,621
Wire and wire rods	*33,924	*36,163	*39,024	*37,608	38,965
Pipe and tube	*23,993	33,341	*33,800	*42,837	43,743
Total	*271,223	*285,017	312,112	*334,767	340,015

¹Revised.

²Data for 1989-91 are included in table 10. Data for 1987-88 are based on tariff schedule of the United States.

Source: International Trade Commission.

TABLE 12
U.S. SHIPMENTS OF IRON AND STEEL CASTINGS

(Thousand metric tons)

	1987	1988	1989	1990	1991
Ductile iron castings	2,770	2,912	3,013	2,890	2,530
Gray iron castings	5,172	5,390	5,115	4,602	3,978
Malleable iron castings	291	293	271	263	237
Steel castings	919	1,077	1,074	1,028	908
Steel investment castings	34	43	43	36	32
Total	9,186	*9,714	9,516	8,819	7,685

¹Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 13
COAL AND COKE AT COKE PLANTS¹

(Thousand metric tons)

	1987	1988	1989	1990	1991
Coal: Consumption	33,527	38,000	36,748	35,269	30,712
Coke: ²					
Production	23,863	26,258	25,442	25,054	21,814
Exports	521	992	984	519	671
Imports	836	2,439	2,097	694	997
Consumption, apparent	25,087	27,234	26,248	25,230	21,968

¹Includes furnace and merchant coke plants.

²Coke production and consumption do not include breeze.

Source: Energy Information Administration, Quarterly Coal Report (DOE/EIA-0121).

TABLE 14
PIG IRON¹ AND DIRECT-REDUCED IRON:² WORLD PRODUCTION, BY COUNTRY³

(Thousand metric tons)

Country ⁴	1987	1988	1989	1990	1991 ⁵
Albania	140	172	179	96	50
Algeria	1,360	¹ 1,500	¹ 1,301	¹ 1,037	1,000
Argentina:					
Pig iron	1,752	1,596	² 2,062	1,933	¹ 1,366
Direct-reduced iron	¹ 1,034	1,067	¹ 1,166	1,035	² 954
Australia	5,569	5,730	⁶ 6,094	⁶ 6,125	⁵ 5,647
Austria	3,451	3,665	3,823	³ 3,452	³ 3,439
Belgium	8,244	9,147	8,863	⁹ 9,416	⁹ 9,373
Brazil:					
Pig iron	21,307	23,366	24,363	21,167	22,695
Direct-reduced iron	202	195	258	260	260
Bulgaria	1,652	1,437	¹ 1,484	¹ 1,143	800
Burma:					
Pig iron	1	1	4	(⁶)	3
Direct-reduced iron	20	20	20	² 20	20
Canada:					
Pig iron	9,719	9,498	¹⁰ 10,139	⁷ 7,346	⁸ 8,268
Direct-reduced iron	727	747	⁷ 710	⁷ 730	⁵ 560
Chile	617	776	679	⁶ 675	⁷ 703
China	55,030	57,040	⁵⁸ 58,200	⁶² 62,380	67,000
Colombia	326	309	297	323	300
Czechoslovakia	9,788	9,706	9,911	⁹ 9,667	⁸ 8,479
Egypt:					
Pig iron	¹ 1,069	¹ 1,112	¹ 1,105	¹ 1,100	1,250
Direct-reduced iron	472	699	⁸ 817	⁷ 710	620
Finland	2,063	2,174	2,284	² 2,283	² 2,331
France	¹³ 13,449	¹⁴ 14,786	¹⁵ 15,071	¹⁴ 14,415	¹³ 13,645
Germany, Federal Republic of:					
Pig iron:					
Eastern states ⁷	2,755	2,786	² 2,732	² 2,159	NA
Western states	28,517	32,453	32,777	³⁰ 30,098	NA
Total	31,272	35,239	³⁵ 35,509	³² 32,257	³⁰ 30,989
Direct-reduced iron: Western states	200	270	³ 353	³ 310	260
Greece ⁶	160	160	160	160	160
Hungary	2,107	2,093	1,954	¹ 1,697	¹ 1,311
India:					
Pig iron	10,893	11,735	12,080	¹² 12,645	14,176
Direct-reduced iron	190	190	340	⁷ 750	1,180
Indonesia: Direct-reduced iron	919	980	1,262	¹ 1,300	1,350
Iran:					
Pig iron ⁶	250	250	250	⁵ 1,267	¹ 1,952
Direct-reduced iron	—	—	70	³ 300	⁵ 580
Iraq: Direct-reduced iron ⁶	—	20	200	¹ 170	20
Italy	11,335	11,349	¹¹ 11,795	¹¹ 11,803	¹⁰ 10,862
Japan	73,418	79,295	80,197	80,229	⁷⁹ 79,985
Korea, North ⁶	5,800	6,500	6,500	6,500	6,500
Korea, Republic of	11,057	12,578	14,846	15,339	18,510

See footnotes at end of table.

TABLE 14—Continued
PIG IRON¹ AND DIRECT-REDUCED IRON:² WORLD PRODUCTION, BY COUNTRY³

(Thousand metric tons)

Country ⁴	1987	1988	1989	1990	1991 ⁵
Libya: Direct-reduced iron ⁶	—	—	90	¹ 500	777
Luxembourg ⁷	2,305	2,521	2,685	² 2,616	2,600
Malaysia: Direct-reduced iron	591	454	570	⁶ 600	600
Mexico:					
Pig iron	3,712	3,678	3,230	3,665	3,000
Direct-reduced iron	1,551	1,686	2,148	2,525	2,500
Morocco ⁸	15	15	15	15	15
Netherlands	4,575	4,994	5,163	4,960	⁴ 4,734
New Zealand: Direct-reduced iron ⁸	—	⁴ 418	⁴ 493	⁵ 549	594
Nigeria: Direct-reduced iron	140	145	¹ 143	¹ 140	140
Norway	360	367	² 270	⁵ 54	61
Pakistan	897	933	¹ 1,000	¹ 1,000	1,100
Paraguay	50	63	63	⁶ 61	60
Peru:					
Pig iron	185	202	227	¹ 117	180
Direct-reduced iron	51	49	⁵ 50	⁵ 50	50
Poland	10,476	10,264	9,488	⁸ 8,658	6,355
Portugal	⁵ 530	⁵ 545	377	³ 339	² 251
Qatar: Direct-reduced iron	472	443	531	⁵ 530	530
Romania	8,673	⁸ 8,941	⁹ 9,052	⁶ 6,355	4,500
Saudi Arabia: Direct-reduced iron	1,315	980	¹ 1,205	¹ 1,200	1,200
South Africa, Republic of:					
Pig iron	6,317	6,171	6,543	6,257	⁶ 6,968
Direct-reduced iron	844	730	840	⁹ 900	⁹ 900
Spain	4,804	4,639	5,722	⁵ 5,542	5,588
Sweden	² 2,314	2,494	2,637	2,736	² 2,812
Switzerland ⁸	70	70	70	70	70
Taiwan	³ 3,900	5,675	5,780	5,474	⁵ 5,561
Trinidad and Tobago:					
Direct-reduced iron	475	⁵ 593	612	697	700
Tunisia ⁸	150	150	150	150	150
Turkey	⁴ 4,100	⁴ 4,462	³ 3,523	⁴ 4,827	⁴ 4,594
U.S.S.R.:					
Pig iron	¹ 113,877	114,558	¹ 113,928	¹ 110,163	91,000
Direct-reduced iron	1,261	1,600	¹ 1,700	¹ 1,600	1,500
United Kingdom	12,017	13,056	12,638	¹ 12,277	¹ 12,094
United States:					
Pig iron	⁴ 43,824	50,571	50,687	49,668	⁴ 44,123
Direct-reduced iron	210	290	290	360	⁴ 410
Venezuela:					
Pig iron	473	503	489	³ 314	—
Direct-reduced iron	3,151	² 2,710	2,773	¹ 3,130	4,050
Yugoslavia	2,867	2,916	2,899	2,313	1,600
Zimbabwe ⁸	575	600	520	⁵ 521	520

See footnotes at end of table.

TABLE 14—Continued
PIG IRON¹ AND DIRECT-REDUCED IRON:² WORLD PRODUCTION, BY COUNTRY³

(Thousand metric tons)

Country ⁴	1987	1988	1989	1990	1991 ⁵
Grand total	<u>'522,720</u>	<u>'553,888</u>	<u>'562,947</u>	<u>'550,973</u>	<u>528,485</u>
Of which:					
Pig iron	'508,895	'539,602	'546,306	'532,607	508,730
Direct reduced iron	'13,825	'14,286	'16,641	'18,366	19,755

⁴Estimated. Revised. NA Not available.

¹Production is pig iron unless otherwise specified.

²Direct-reduced iron is obtained from ore by reduction of oxides to metal without melting.

³Table excludes ferroalloy production except where otherwise noted. Table includes data available through July 2, 1992.

⁴In addition to the countries listed, Vietnam and Zaire have facilities to produce pig iron and may have produced limited quantities during 1987-91, but output is not reported and available information is inadequate to make reliable estimates of output levels.

⁵Reported figure.

⁶Less than 500 tons.

⁷Includes blast furnace ferroalloys.

⁸Previously listed as estimated pig iron production.

TABLE 15
RAW STEEL:¹ WORLD PRODUCTION, BY COUNTRY²

(Thousand metric tons)

Country ³	1987	1988	1989	1990	1991 [*]
Albania [*]	'85	'110	'112	'65	35
Algeria	'1,378	'1,301	'943	'767	700
Angola [*]	10	10	10	10	10
Argentina	3,633	'3,652	'3,909	'3,634	'2,966
Australia	6,129	6,399	6,735	6,666	'6,018
Austria	4,301	4,560	4,718	4,292	4,186
Bangladesh ⁵	82	81	86	90	90
Belgium	9,787	11,222	10,948	11,426	'11,332
Brazil	22,231	24,536	25,018	20,572	22,617
Bulgaria	'3,045	2,875	2,899	'2,185	2,000
Canada	'14,737	'14,866	'15,458	'12,281	'12,987
Chile	726	909	800	'772	'805
China	'56,280	'59,430	61,200	'66,100	'70,570
Colombia	689	754	706	733	700
Cuba	402	314	336	270	270
Czechoslovakia	15,356	15,319	15,465	'14,877	'12,133
Denmark	606	650	625	610	'633
Dominican Republic	88	75	55	36	'39
Ecuador	25	24	23	'20	'20
Egypt	'1,433	'2,025	'2,114	'2,235	2,541
El Salvador	13	11	'12	'13	12
Finland	2,669	2,798	2,921	2,861	2,456
France	'17,693	'19,122	'19,335	'19,032	'18,437
Germany, Federal Republic of:					
Eastern states	8,243	8,131	7,829	5,587	NA
Western states	36,248	41,023	41,073	38,435	NA
Total	44,491	49,154	48,902	44,022	'42,169
Greece	907	959	958	'1,050	'980
Guatemala	21	23	23	'23	20
Honduras [*]	7	7	'8	'8	8
Hong Kong [*]	280	300	320	350	350
Hungary	3,621	3,583	3,356	'2,963	1,900
India ⁶	'13,121	'14,309	'14,608	'14,963	16,394
Indonesia	1,453	2,050	'2,400	'2,800	3,250
Iran	'839	'978	'1,081	'1,425	'2,203
Iraq [*]	—	50	300	150	20
Ireland	220	271	324	326	'293
Israel [*]	'116	120	118	144	164
Italy	22,859	23,760	25,213	25,439	'25,007
Jamaica	'21	'28	'37	'24	25
Japan	98,513	105,681	107,908	110,339	'109,649
Jordan	'240	17	14	'14	14
Korea, North [*]	6,500	8,000	8,000	8,000	8,000
Korea, Republic of	16,782	19,117	21,873	23,125	26,001
Libya	—	—	—	500	500
Luxembourg	3,301	3,659	3,721	3,561	'3,379
Malaysia [*]	'750	550	'880	'900	900

See footnotes at end of table.

TABLE 15—Continued
RAW STEEL:¹ WORLD PRODUCTION, BY COUNTRY²

(Thousand metric tons)

Country ³	1987	1988	1989	1990	1991 ⁴
Mexico	7,642	7,779	7,851	⁸ 8,726	⁷ 8,883
Morocco ⁵	6	7	7	7	7
Netherlands	5,082	5,518	5,681	5,412	⁵ 5,174
New Zealand	409	460	608	765	700
Nigeria	184	192	213	220	200
Norway	837	907	641	384	438
Pakistan ⁶	1,100	1,000	1,000	1,000	1,000
Paraguay	13	62	⁶ 63	⁶ 63	60
Peru	503	481	401	² 284	350
Philippines ⁶	250	³ 331	300	300	250
Poland	17,148	16,873	15,094	¹ 3,625	¹ 0,439
Portugal	732	811	⁷ 762	⁷ 746	⁵ 564
Qatar	492	527	585	571	550
Romania	13,885	¹ 4,496	14,415	⁹ 9,787	7,000
Saudi Arabia	1,365	1,614	1,810	1,833	1,850
Singapore	422	413	495	489	490
South Africa, Republic of	8,991	8,837	⁹ 9,337	⁸ 8,691	⁹ 9,358
Spain	11,691	11,685	12,684	12,705	12,700
Sweden	4,595	4,779	⁴ 4,700	4,454	4,248
Switzerland	870	825	916	970	955
Syria ⁶	70	70	70	70	70
Taiwan	5,949	8,313	9,047	⁹ 9,747	¹ 0,957
Thailand	534	552	689	685	711
Trinidad and Tobago	361	³ 361	294	³ 372	425
Tunisia	196	150	194	200	200
Turkey	7,044	7,982	7,934	⁹ 9,462	⁹ 9,336
U.S.S.R.	161,887	163,037	¹ 60,096	¹ 54,414	132,666
United Kingdom	17,425	19,013	18,813	17,908	¹ 6,511
United States	80,877	90,650	88,852	89,726	⁷ 9,738
Uruguay	30	29	47	40	40
Venezuela ⁶	³ 3,297	³ 3,165	² 2,941	³ 3,000	3,100
Vietnam ⁶	110	115	115	120	120
Yugoslavia	4,367	4,487	4,500	3,609	2,200
Zimbabwe	515	602	592	580	600
Total	⁷734,319	⁷779,782	⁷86,219	⁷70,638	733,673

⁵Estimated. ⁶Revised. NA Not available.

¹Steel formed in first solid state after melting, suitable for further processing or sale; for some countries, includes material reported as "liquid steel," presumably measured in the molten state prior to cooling in any specific form.

²Table includes data available through June 29, 1992.

³In addition to the countries listed, Burma, Ghana, Libya, and Mozambique are known to have steelmaking plants, but available information is inadequate to make reliable estimates of output levels.

⁴Reported figure.

⁵Data are for year ending June 30 of that stated.

⁶Includes steel castings.

TABLE 16
GOVERNMENT INVENTORY OF FERROALLOYS,
DECEMBER 31, 1991

(Metric tons of alloy, unless otherwise stated)

Alloy	Stock- pile grade	Non- stock- pile grade	Total
Ferrochromium:			
High-carbon	670,865	629	671,494
Low-carbon	272,373	15,357	287,730
Ferrochromium-silicon	51,699	1,242	52,941
Ferrocolumbium (kilograms contained columbium)	271,435	150,820	422,255
Ferromanganese:			
High-carbon	942,813	—	942,813
Medium-carbon	26,374	—	26,374
Ferrotungsten (kilograms contained tungsten)	381,359	536,778	918,137
Silicomanganese	21,386	—	21,386

TABLE 17
HISTORICAL FERROALLOY
PRICE TRENDS

(Weighted annual averages)

Year	FeMn ¹	FeCr ²	FeSi ³
1977	327.20	36.25	28.55
1978	334.11	33.11	29.96
1979	440.14	43.03	41.70
1980	428.37	45.85	41.77
1981	410.97	46.37	40.01
1982	396.23	46.01	37.93
1983	328.21	36.71	36.67
1984	331.60	43.21	41.89
1985	330.21	43.71	35.71
1986	319.22	39.94	33.65
1987	341.80	43.89	36.78
1988	510.23	85.08	56.82
1989	619.64	75.67	48.96
1990	644.27	47.51	39.94
1991	602.92	47.32	36.98

¹Imported standard-grade ferromanganese—prices in dollars per long ton of alloy.

²Imported charge-grade ferrochromium—prices in cents per pound of contained chromium.

³Imported 75%-grade ferrosilicon—prices in cents per pound of contained silicon.

TABLE 18
PRODUCERS OF FERROALLOYS IN THE UNITED STATES IN 1991

Producer	Plant location	Products ¹	Type of furnace
FERROALLOYS (except ferrophosphorus)			
Alabama Silicon Inc.	Bessemer, AL	FeSi	Electric.
AMAX Inc., Climax Molybdenum Co. Div.	Langeloth, PA	FeMo	Metallothermic.
American Alloys, Inc.	New Haven, WV	FeSi, Si	Electric.
Applied Industrial Minerals Corp. (AIMCOR)	Bridgeport, Al, Kimball, TN	FeSi, other ²	Do.
Bear Metallurgical Inc.	Butler, PA	FeMo, FeV	Metallothermic.
Cabot Corp.	Revere, PA	FeCb	Do.
Cyprus Minerals Co.	Sahuarita, AZ	FeMo	Do.
Dow Corning Corp.	Springfield, OR	Si	Electric.
Elkem A/S, Elkem Metals Co.	Alloy, WV, Ashtabula, OH, Marietta, OH, Niagara Falls, NY	Cr, FeB, FeCr, FeMn, FeSi, Mn, Si, SiMn, other ²	Electric and electrolytic.
Galt Alloys Inc.	Canton, OH	FeTi, FeAl	NA.
Globe Metallurgical Inc.	Beverly, OH, Selma, AL	FeSi, Si	Electric.
HTP Co.	Sharon, PA	FeTi	Metallothermic.
Keokuk Ferro-Sil Inc.	Keokuk, IA	FeSi, silvery pig iron	Electric.
Kerr-McGee Chemical Corp.	Hamilton (Aber- deen), MS	Mn	Electrolytic.
Macalloy Corp.	Charleston, SC	FeCr	Electric.
Metallurg Inc., Shieldalloy Metallurgical Corp.	Cambridge, OH, Newfield, NJ	Cr, FeAl, FeB, FeCb, FeTi, FeV, other ²	Electric and metallothermic.
Reading Alloys Inc.	Robesonia, PA	FeCb, FeV	Metallothermic.
Reynolds Metals Co.	Sheffield, AL	Si	Electric.
Satra Concentrates	Steubenville, OH	FeCr	Slag conversion.
Silicon Metaltech Inc.	Wenatchee, WA	FeSi, Si	Electric.
Simetco	Montgomery, AL	Si	Do.
SKW Alloys Inc.	Calvert City, KY, Niagara Falls, NY	FeCrSi, SiMn, FeSi, Si	Do.
Strategic Minerals Corp. (STRATCOR), U.S. Vanadium Corp.	Niagara Falls, NY	FeV, FeW	Do.
Teledyne Inc., Teledyne Wah Chang, Albany Div.	Albany, OR	FeCb	Metallothermic.
Union Oil Co. of California, Molycorp Inc.	Washington, PA	FeB, FeMo	Electric and metallothermic.
Universal Consolidated Co., Nickel Mountain Resources	Riddle, OR	FeNi, FeSi	Electric.
FERROPHOSPHORUS			
FMC Corp., Industrial Chemical Div.	Pocatello, ID	FeP	Do.
Monsanto Co., Monsanto Industrial Chemicals Co.	Soda Springs, ID	do.	Do.
Occidental Petroleum Corp.	Columbia, TN	do.	Do.
Rhone Poulenc Basic Chemical Co.	Butte, MT, Mount Pleasant, TN	do.	Do.

NA Not available.

¹Cr, chromium metal; FeAl, ferroaluminum; FeB, ferroboreon; FeCb, ferrocolumbium; FeCr, ferrochromium; FeCrSi, ferrochromium-silicon; FeMn, ferromanganese; FeMo, ferromolybdenum; FeNi, ferronickel; FeP, ferrophosphorus; FeSi, ferrosilicon; FeTi, ferrotitanium; FeV, ferrovanadium; FeW, ferrotungsten; FeZr, ferrozirconium; Mn, manganese metal; Si, silicon metal; SiMn, silicomanganese.

²Includes specialty silicon alloys, zirconium alloys, and miscellaneous ferroalloys.

TABLE 19
U.S. FERROALLOY PRODUCTION¹ AND SHIPMENTS²

(Metric tons, gross weight, unless otherwise specified)

	1991			
	Net production	Net shipments		Stocks, December 31
		Quantity	Value (thousands)	
Ferrosilicon ³	338,154	364,059	\$191,432	80,962
Silicon metal	145,275	138,401	187,239	19,062
Other ⁴	257,711	252,687	410,295	44,888
Ferrophosphorus	36,135	31,836	5,396	20,761
Total⁵	777,273	786,981	794,363	165,673

¹Does not include alloys produced for consumption in the making of other ferroalloys.

²Gross sales (including exports) minus purchases.

³Includes all regular and specialty grades of ferrosilicon, excluding silvery pig iron.

⁴Includes ferroaluminum, ferroboron and other complex boron additive alloys, all chromium-containing ferroalloys and chromium metal, ferrocolumbium, all manganese-containing ferroalloys and manganese metal, ferromolybdenum, ferronickel, ferrotitanium, ferrovanadium, and silvery pig iron.

⁵Data may not add to totals shown because of independent rounding.

TABLE 20
REPORTED U.S. CONSUMPTION OF FERROALLOYS AS ADDITIVES IN 1991, BY END USE¹

(Metric tons of alloys unless otherwise specified)

End use	FeMn	SiMn	FeSi	FeTi	FeP	FeB
Steel:						
Carbon	266,839	71,208	² 50,427	1,479	5,938	482
Stainless and heat-resisting	² 14,565	5,572	² 87,761	1,927	(³)	24
Other alloy	² 55,583	20,865	² 51,625	170	1,121	230
Tool	136	(³)	² 1,269	(³)	(³)	—
Unspecified	1,044	354	9,408	6	4	—
Total steel⁴	338,168	97,999	200,492	3,582	7,062	737
Cast irons	10,088	1,530	¹ 166,105	34	1,217	7
Superalloys	¹ 118	—	¹ 118	688	—	W
Alloys (excluding alloy steels and superalloys)	18,191	W	³ 9,999	665	W	183
Miscellaneous and unspecified	2,169	2,808	168,723	9	181	29
Total⁴	368,734	102,336	539,435	4,977	8,461	956
Percent of 1990	85	104	77	83	85	98
Consumer stocks, December 31	⁶ 55,302	⁶ 8,490	15,012	581	1,383	186

W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

¹FeMn, ferromanganese, including spiegeleisen and manganese metal; SiMn, silicomanganese; FeSi, ferrosilicon, including silicon metal, silvery pig iron, and inoculant alloys; FeTi, ferrotitanium; FeP, ferrophosphorus; FeB ferroboron, including other boron materials.

²Part included with "Steel: Unspecified."

³Included with "Steel: Unspecified."

⁴Data may not add to total shown because of independent rounding.

⁵Part included with "Miscellaneous and unspecified."

⁶Includes some producer stocks.

TABLE 21
REPORTED U.S. CONSUMPTION OF FERROALLOYS AS ALLOYING ELEMENTS IN 1991, BY END USE¹

(Metric tons of contained elements unless otherwise specified)

End use	FeCr	FeMo	FeW	FeV	FeCb	FeNi
Steel:						
Carbon	6,601	121	—	920	603	—
Stainless and heat-resisting	163,310	223	44	37	338	13,722
Other alloy	² 18,730	(³)	(³)	1,659	971	223
Tool	1,924	168	243	242	(³)	—
Unspecified	(³)	(³)	(³)	(³)	16	—
Total steel⁵	190,565	512	287	2,858	1,928	13,945
Cast irons	² 2,456	543	(³)	16	(³)	—
Superalloys	4,412	47	13	15	463	—
Alloys (excluding alloy steels and superalloys)	908	81	(³)	357	17	—
Miscellaneous and unspecified	3,216	60	146	40	1	—
Total⁵	201,556	1,243	445	3,286	2,409	13,945
Percent of 1990	94	77	91	80	93	80
Consumer stocks, December 31	10,853	9,387	42	400	NA	1,361

NA Not available. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

¹FeCr, ferrochromium, including other chromium ferroalloys and chromium metal; FeMo, ferromolybdenum, including calcium molybdate; FeW, ferrotungsten, including scheelite; FeV, ferrovandium, including other vanadium-carbon-iron ferroalloys; FeCb, ferrocolumbium, including nickel columbium; FeNi, ferronickel.

²Part included with "Miscellaneous and unspecified."

³Included with "Miscellaneous and unspecified."

⁴Included with "Steel: Unspecified."

⁵Data may not add to totals shown because of independent rounding.

TABLE 22
FERROALLOY PRICES IN 1991

	High	Low	Average ¹
Standard-grade ferromanganese ²	650.00	555.00	602.92
Medium-carbon ferromanganese ³	57.00	51.50	54.16
Silicomanganese ⁴	28.00	23.60	26.00
Charge-grade ferrochromium ³	50.00	44.50	47.32
High-carbon ferrochromium ³	52.50	42.50	46.81
Low-carbon ferrochromium ³	107.00	89.00	98.67
50%-grade ferrosilicon ³	42.50	35.00	38.41
75%-grade ferrosilicon ³	40.50	31.75	36.98
Silicon metal ⁴	66.50	54.00	61.65
Ferromolybdenum ⁵	3.84	3.15	3.43
Molybdenum oxide ⁵	2.78	2.08	2.38
Ferrovandium ⁶	14.95	11.20	12.66

¹Annual weighted average.

²Dollars per long ton.

³Cents per pound of contained element.

⁴Cents per pound.

⁵Dollars per pound of contained element.

⁶Dollars per kilogram of contained element.

TABLE 23
**U.S. EXPORTS OF FERROALLOYS AND FERROALLOY METALS IN
 1991**

Alloy	Quantity (metric tons)	Content (metric tons)	Value (thou- sands)
Ferroalloys:			
Ferrochromium with greater than 4% carbon	7,820	4,617	\$7,166
Ferrochromium with less than 4% carbon	2,084	1,263	3,602
Ferrochromium-silicon	745	261	939
Ferrocolumbium	741	(1)	6,952
Ferromanganese with greater than 2% carbon	4,571	3,611	3,106
Ferromanganese, other	10,002	7,871	12,308
Silicomanganese	2,873	1,868	2,802
Ferromolybdenum	375	225	3,058
Ferronickel	1,900	1,140	5,590
Ferrophosphorus	2,872	(1)	1,822
Ferrosilicon (greater than 55% silicon)	14,831	9,001	14,209
Ferrosilicon, other	35,563	17,751	28,798
Ferrovandium	178	94	2,454
Ferrozirconium	95	(1)	138
Ferrotungsten and ferrosilicon-tungsten	65	32	161
Ferroalloys, n.e.c.	2,800	(1)	4,112
Total ferroalloys	<u>87,515</u>	<u>XX</u>	<u>97,217</u>
Metals:			
Chromium	424	(1)	4,691
Manganese	5,272	(1)	12,658
Silicon:			
Less than 99% silicon	5,281	5,125	7,465
99% to 99.99% silicon	1,454	1,441	2,014
Greater than 99.99% silicon	1,511	1,511	102,843
Total ferroalloy metals	<u>13,942</u>	<u>XX</u>	<u>129,671</u>
Grand total	<u>101,457</u>	<u>XX</u>	<u>226,888</u>

XX Not applicable.

(1) Not recorded.

Source: Bureau of the Census.

TABLE 24
U.S. IMPORTS FOR CONSUMPTION OF FERROALLOYS AND FERROALLOY METALS IN 1991

(Metric tons and thousand dollars)

Alloy	Gross weight	Content	Value
Chromium alloys:			
Ferrochromium containing 4% or more carbon	361,998	206,771	\$180,622
Ferrochromium containing less than 4%, but greater than 3% carbon	86	58	113
Ferrochromium containing less than 3% carbon	38,453	25,572	50,924
Ferrochromium-silicon	5,301	2,046	3,517
Total chromium alloys	405,838	234,447	235,176
Manganese alloys:			
Ferromanganese containing more than 4% carbon	251,151	194,205	126,151
Ferromanganese containing more than 2% to 4% carbon	—	—	—
Ferromanganese containing more than 1% to 2% carbon	55,045	44,152	43,602
Ferromanganese containing 1% or less carbon	13,584	12,116	19,409
Silicomanganese	258,293	169,784	130,677
Total manganese alloys	578,073	420,257	319,839
Silicon alloys:			
Less than 55% silicon containing more than 2% magnesium	860	404	1,707
Less than 55% silicon, n.e.c.	46,367	20,044	14,049
55% to 80% silicon, containing more than 3% calcium	13,700	9,498	11,836
55% to 80% silicon, n.e.c.	122,218	91,148	65,835
80% to 90% silicon	69	59	28
Greater than 90% silicon	—	—	—
Total silicon alloys	183,214	121,153	93,455
Other ferroalloys:			
Ferrocerium and other cerium alloys	167	(1)	1,615
Ferromolybdenum	1,521	953	7,304
Ferronickel	39,810	14,547	113,267
Ferroniobium (columbium)	3,282	(1)	27,415
Ferrophosphorus	6,713	(1)	1,835
Ferrotitanium and ferrosilicon titanium	1,166	(1)	3,819
Ferrotungsten and ferrosilicon tungsten	690	525	3,128
Ferrovandium	534	428	5,464
Ferrozirconium	288	(1)	483
Ferroalloys, n.e.c.	16,485	(1)	24,749
Total other ferroalloys	70,656	XX	189,079
Total ferroalloys	1,237,781	XX	837,549
Metals:			
Chromium	5,747	(1)	43,617
Manganese, unwrought	9,632	(1)	14,887
Manganese, other	6,057	(1)	9,565
Silicon, less than 99% silicon	14,513	14,257	13,790
Silicon 99 to 99.99% silicon	28,062	27,821	32,970
Silicon, greater than 99.99% silicon	811	811	53,613
Total ferroalloy metals	64,822	XX	168,442
Grand total	1,302,603	XX	1,005,991

XX Not applicable.
(1) Not recorded.

Source: Bureau of the Census.

TABLE 25
FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE¹

(Metric tons)

Country, furnace type, ² and alloy type ³	1987	1988	1989	1990	1991 ⁴
Albania: Electric furnace, ferrochromium	26,300	33,700	38,800	24,000	35,000
Argentina: Electric furnace:					
Ferromanganese	21,407	19,737	25,545	23,787	23,800
Silicomanganese	11,746	11,610	16,857	21,536	21,500
Ferrosilicon	23,998	30,539	28,381	17,509	17,500
Silicon metal ⁵	10,000	10,000	10,000	10,000	10,000
Other	6,362	5,744	5,603	7,124	7,200
Total⁶	73,513	77,630	86,386	79,956	80,000
Australia: Electric furnace:					
Ferromanganese	51,000	58,000	67,000	70,000	55,000
Silicomanganese ⁷	43,000	44,000	55,000	65,000	50,000
Ferrosilicon	18,000	18,000	20,000	20,000	20,000
Silicon metal ⁸	2,000	8,000	9,000	33,000	30,000
Total	114,000	128,000	151,000	188,000	155,000
Austria: Electric furnace, other	7,000	20,000	15,000	12,000	12,000
Belgium: Electric furnace, ferromanganese⁹	90,000	95,000	95,000	90,000	90,000
Brazil: Electric furnace:					
Ferromanganese	155,252	180,588	180,668	170,504	169,103
Silicomanganese	188,022	193,490	208,262	216,779	272,046
Ferrosilicon	231,159	267,538	286,994	229,408	190,864
Silicon metal	39,982	79,287	116,779	131,614	106,002
Ferrochromium	105,394	130,024	113,267	83,753	82,225
Ferrochromium-silicon	8,079	9,177	8,938	4,973	4,524
Ferronickel	35,496	33,930	34,997	34,257	33,281
Other	60,454	79,090	81,901	68,026	77,235
Total	823,838	973,124	1,031,806	939,314	935,280
Bulgaria: Electric furnace:¹⁰					
Ferromanganese ¹¹	31,000	31,000	30,000	—	—
Ferrosilicon	10,000	15,000	14,000	14,000	14,000
Other	1,000	1,000	1,000	1,000	1,000
Total	42,000	47,000	45,000	15,000	15,000
Canada: Electric furnace:¹²					
Ferromanganese ¹³	165,000	161,000	185,000	185,000	45,000
Ferrosilicon	95,191	90,266	88,370	90,000	106,850
Other	76,900	66,300	106,000	100,000	95,000
Total	337,091	317,566	379,370	375,000	246,850
Chile: Electric furnace:					
Ferromanganese	6,613	6,935	7,492	7,000	6,600
Silicomanganese	1,231	683	180	200	700
Ferrosilicon	4,655	5,686	6,370	5,800	5,600
Ferrochromium	475	2,212	2,840	2,500	2,000
Other	1,325	1,191	2,990	3,000	3,100
Total	14,299	16,707	19,872	18,500	18,000
China:					
Blast furnace:					
Ferromanganese ¹⁴	200,000	220,000	240,000	240,000	250,000
Other	194,400	186,000	160,000	170,000	170,000

See footnotes at end of table.

TABLE 25—Continued
FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE¹

(Metric tons)

Country, furnace type, ² and alloy type ³	1987	1988	1989	1990	1991 ⁴
China—Continued:					
Electric furnace:					
Ferromanganese	115,900	89,000	*120,000	*130,000	140,000
Silicomanganese ⁶	220,000	220,000	240,000	240,000	250,000
Ferrosilicon	591,200	787,600	900,000	900,000	950,000
Ferrochromium	(⁷)	(⁷)	*350,000	(⁷)	(⁷)
Other	524,500	581,400	372,000	720,000	790,000
Total	1,846,000	2,084,000	2,382,000	2,400,000	2,550,000
Colombia: Electric furnace, ferronickel	46,389	41,672	41,454	43,847	44,000
Czechoslovakia: Electric furnace:					
Ferromanganese ⁵	96,952	95,087	100,159	*101,660	90,000
Ferrosilicon	21,030	22,730	20,997	20,474	15,000
Silicon metal ⁶	5,000	5,000	5,000	5,000	5,000
Ferrochromium	29,018	29,183	29,844	31,866	30,000
Other ⁷	9,000	10,000	10,000	*10,000	10,000
Total	161,000	162,000	166,000	*169,000	150,000
Dominican Republic: Electric furnace, ferronickel	81,303	73,363	78,160	71,753	60,000
Egypt: Electric furnace, ferrosilicon	7,702	7,806	*7,800	*7,922	7,900
Finland: Electric furnace, ferrochromium	143,000	156,000	169,000	*152,000	150,000
France:					
Blast furnace:					
Ferromanganese	295,821	323,945	346,295	319,930	320,000
Electric furnace:					
Ferromanganese	23,200	22,000	*27,000	*36,640	30,000
Silicomanganese ⁶	31,200	59,000	*59,000	*61,900	30,000
Ferrosilicon	155,000	*196,000	190,000	*117,490	120,000
Silicon metal ⁶	70,000	70,000	72,000	*64,000	70,000
Ferrochromium	*1,000	*10,000	*20,000	*25,000	20,000
Other ⁹	70,000	60,000	60,000	70,000	50,000
Total	646,221	*740,945	*774,295	*694,960	640,000
Germany:					
Blast furnace, Western states:⁸					
Ferromanganese	156,000	209,000	230,000	*230,000	200,000
Ferrosilicon	40,000	65,000	75,000	*120,000	125,000
Electric furnace:⁸					
Ferromanganese ⁵					
Eastern states	65,000	67,000	67,000	65,000	NA
Western states	25,000	35,000	45,000	*38,000	NA
Total	90,000	102,000	112,000	103,000	95,000
Ferrosilicon:					
Eastern states	24,000	25,000	25,000	24,000	NA
Western states	40,000	50,000	55,000	*46,000	NA
Total	64,000	75,000	80,000	70,000	68,000
Silicon metal, Eastern states	3,000	3,400	3,000	3,000	2,600

See footnotes at end of table.

TABLE 25—Continued
FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE¹

(Metric tons)

Country, furnace type, ² and alloy type ³	1987	1988	1989	1990	1991 ⁴
Germany—Continued:					
Electric furnace—Continued:					
Ferrochromium:					
Eastern states	21,000	22,000	22,000	21,000	NA
Western states	50,000	60,000	65,000	*53,000	NA
Total	71,000	82,000	87,000	74,000	71,000
Other:⁷					
Eastern states	14,000	13,600	13,000	12,000	NA
Western states	57,000	62,000	66,000	*54,000	NA
Total	71,000	75,600	79,000	66,000	65,400
Grand total	495,000	612,000	666,000	666,000	627,000
Greece: Electric furnace:					
Ferrochromium	*49,000	*44,150	*43,500	*30,300	25,000
Ferronickel	35,400	50,500	61,900	*50,000	50,000
Total	*84,400	*94,650	*105,400	*80,300	75,000
Hungary: Electric furnace:⁸					
Ferrosilicon	*9,300	*10,100	*10,200	9,000	9,000
Silicon metal	2,000	2,000	2,000	2,000	2,000
Other	2,000	1,000	1,000	1,000	1,000
Total	*13,300	*13,100	*13,200	12,000	12,000
Iceland: Electric furnace, ferrosilicon	60,184	70,051	72,008	62,791	*50,299
India: Electric furnace:					
Ferromanganese	173,259	138,331	*157,766	*160,000	160,000
Silicomanganese	37,504	52,895	*72,229	*75,000	75,000
Ferrosilicon	50,747	46,721	*74,472	*75,000	75,000
Silicon metal	1,445	686	—	—	—
Ferrochromium	*126,227	*140,261	*135,165	*130,000	130,000
Ferrochromium-silicon	12,321	2,769	11,384	*7,000	2,000
Other	529	445	*442	*400	400
Total	*402,032	*382,108	*451,458	*447,400	442,400
Indonesia: Electric furnace, ferronickel	8,354	26,852	26,058	25,025	25,000
Italy:					
Blast furnace ferroalloys:					
Spiegeleisen	491	251	—	—	—
Ferromanganese	—	—	—	—	—
Electric furnace:					
Ferromanganese	*36,536	*39,449	*40,958	*44,842	43,500
Silicomanganese	75,192	*69,000	*47,000	*56,000	55,000
Ferrosilicon	47,075	51,131	65,171	*40,000	40,000
Silicon metal	*19,000	*18,000	*19,000	*18,000	18,000
Ferrochromium	59,045	77,123	81,331	*41,000	40,000
Other ¹⁰	14,500	14,500	15,000	14,500	14,500
Total ⁹	*251,839	*269,454	*268,460	*214,342	211,000
Japan: Electric furnace:					
Ferromanganese	332,286	378,351	394,055	452,434	*463,722
Silicomanganese	91,896	106,970	122,192	77,465	*87,229
Ferrosilicon	73,706	73,767	74,936	62,599	*62,362

See footnotes at end of table.

TABLE 25—Continued
FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE¹

(Metric tons)

Country, furnace type, ² and alloy type ³	1987	1988	1989	1990	1991*
Japan: Electric furnace—Continued:					
Ferrochromium ⁶	263,988	295,406	324,371	293,345	270,786
Ferronickel	203,143	242,276	275,341	234,311	⁴ 295,422
Other ¹¹	8,284	10,293	11,111	12,078	⁴ 12,323
Total	973,303	1,107,063	1,202,006	1,132,232	⁴1,191,844
Korea, North: Electric furnace:					
Ferromanganese ⁵	70,000	70,000	70,000	70,000	70,000
Ferrosilicon	30,000	30,000	30,000	30,000	30,000
Other ⁷	20,000	20,000	20,000	20,000	20,000
Total	120,000	120,000	120,000	120,000	120,000
Korea, Republic of: Electric furnace:					
Ferromanganese	58,044	75,924	85,329	84,000	85,000
Ferrosilicon	12,646	8,909	4,582	2,000	2,000
Other	90,382	89,966	101,818	99,000	100,000
Total	161,072	174,799	191,729	185,000	187,000
Mexico: Electric furnace:					
Ferromanganese	161,331	165,487	168,042	186,328	190,000
Silicomanganese	80,123	80,223	98,852	52,147	50,000
Ferrosilicon	18,060	16,553	9,474	24,536	24,000
Ferrochromium	6,300	9,295	2,569	275	300
Other	852	727	92	250	300
Total	266,666	272,285	279,029	263,536	264,600
New Caledonia: Electric furnace, ferronickel	115,600	146,300	142,500	126,500	137,500
Norway: Electric furnace:					
Ferromanganese	191,992	361,345	220,591	213,266	⁴ 173,212
Silicomanganese	237,277	232,501	270,315	228,310	⁴ 226,737
Ferrosilicon	336,168	380,976	401,116	397,520	⁴ 377,455
Silicon metal	81,460	88,854	100,194	76,601	65,000
Ferrochromium	—	—	—	³ 30,000	90,000
Other ⁸	21,540	¹ 14,000	¹ 14,000	¹ 14,000	14,000
Total	868,437	¹1,077,676	¹1,006,216	³959,697	946,404
Peru: Electric furnace:					
Ferromanganese	1,942	996	¹ 1,145	⁹ 900	1,000
Ferrosilicon	420	625	² 281	⁵ 500	600
Total	2,362	1,621	¹1,426	¹1,400	1,600
Philippines: Electric furnace:⁶					
Ferromanganese	—	—	—	—	5,000
Ferrosilicon	—	—	9,000	10,000	10,000
Ferrochromium	⁴ 7,000	⁵ 9,000	69,000	⁶ 2,000	18,000
Total	⁴7,000	⁵9,000	⁷8,000	⁷2,000	33,000
Poland:					
Blast furnace:					
Spiegeleisen	2,500	1,078	906	140	140
Ferromanganese	95,300	91,117	90,267	71,000	70,000
Electric furnace:					
Ferromanganese ⁵	⁴ 1,100	³ 400	1,427	5,400	5,000

See footnotes at end of table.

TABLE 25—Continued
FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE¹

(Metric tons)

Country, furnace type, ² and alloy type ³	1987	1988	1989	1990	1991 ⁴
Poland—Continued:					
Electric furnace—Continued:					
Ferrosilicon	56,700	58,700	83,210	88,600	80,000
Silicon metal ⁶	10,000	10,000	10,000	10,000	9,000
Ferrochromium	35,900	36,316	24,300	13,700	12,000
Other ⁷	16,000	66,000	60,718	33,100	30,000
Total⁸	220,500	266,611	270,828	221,940	206,140
Portugal: Electric furnace:⁹					
Ferromanganese ¹²	17,000	10,000	13,170	12,480	12,000
Silicomanganese ¹²	8,000	5,000	—	—	—
Ferrosilicon	2,000	—	—	—	—
Silicon metal	3,000	2,500	—	—	—
Total	30,000	17,500	13,170	12,480	12,000
Romania: Electric furnace:⁹					
Ferromanganese	81,000	80,000	80,000	80,000	70,000
Silicomanganese	39,000	40,000	40,000	40,000	20,000
Ferrosilicon	50,000	50,000	50,000	50,000	30,000
Silicon metal	4,500	4,500	4,500	4,500	3,000
Ferrochromium	42,000	42,000	42,000	42,000	30,000
Total	216,500	216,500	216,500	216,500	153,000
South Africa: Electric furnace:⁹					
Ferromanganese	315,000	447,000	403,000	404,000	255,000
Silicomanganese	282,000	248,000	258,000	234,000	245,000
Ferrosilicon	83,000	87,000	93,000	100,000	96,000
Silicon metal	34,000	39,000	36,000	43,000	40,000
Ferrochromium ¹³	965,071	993,685	1,036,000	1,022,000	1,127,000
Other ⁸	1,000	1,000	2,000	1,000	1,000
Total⁸	1,680,071	1,815,685	1,828,000	1,804,000	1,764,000
Spain: Electric furnace:⁹					
Ferromanganese	50,000	48,000	50,000	52,220	50,000
Silicomanganese	35,000	38,000	40,000	38,440	40,000
Ferrosilicon	40,000	36,000	38,000	37,500	40,000
Silicon metal	11,800	10,700	11,500	9,000	9,000
Ferrochromium	16,000	15,000	16,000	15,100	15,000
Other	5,000	5,000	5,000	5,000	5,000
Total	157,800	152,700	160,500	157,260	159,000
Sweden: Electric furnace:⁹					
Ferrosilicon	19,949	20,622	19,303	12,000	12,000
Silicon metal ⁶	20,000	20,000	—	—	—
Ferrochromium	111,815	143,055	151,697	120,000	110,000
Total	151,764	183,677	171,000	132,000	122,000
Switzerland: Electric furnace:⁹					
Ferrosilicon	3,000	3,000	3,000	3,000	3,000
Silicon metal	2,000	2,000	2,000	2,000	2,000
Total	5,000	5,000	5,000	5,000	5,000

See footnotes at end of table.

TABLE 25—Continued
FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE¹

(Metric tons)

Country, furnace type, ² and alloy type ³	1987	1988	1989	1990	1991*
Taiwan: Electric furnace:					
Ferromanganese	17,026	25,822	30,623	43,631	⁴ 40,110
Silicomanganese	18,944	30,745	26,510	20,587	⁴ 12,801
Ferrosilicon	4,058	19,601	19,277	15,501	⁴ 6,252
Total	40,028	76,168	76,410	79,719	⁴59,163
Turkey: Electric furnace:					
Ferrosilicon	4,400	5,200	4,970	⁵ 5,225	5,200
Ferrochromium	52,530	54,030	59,715	⁶ 62,040	78,000
Total	56,930	59,230	64,685	⁶67,265	83,200
U.S.S.R.:					
Blast furnace:					
Spiegeleisen	19,000	18,000	18,000	17,000	15,000
Ferromanganese	593,000	604,000	609,000	600,000	550,000
Ferrophosphorus	25,000	25,000	29,000	25,000	22,000
Electric furnace:^{9 14}					
Ferromanganese	437,800	453,500	414,100	410,000	370,000
Silicomanganese	¹ 1,300,000	¹ 1,300,000	¹ 1,300,000	¹ 1,300,000	1,100,000
Ferrosilicon	1,867,400	1,911,800	1,872,600	1,860,000	1,800,000
Silicon metal	65,000	65,000	65,000	65,000	60,000
Ferrochromium	806,200	925,400	860,800	850,000	800,000
Ferrochromium-silicon	13,500	14,000	14,000	14,000	12,000
Ferronickel	90,000	90,000	90,000	90,000	85,000
Other	150,000	160,000	160,000	160,000	140,000
Total⁹	⁵5,366,900	⁵5,566,700	⁵5,432,500	⁵5,391,000	4,954,000
United Kingdom:					
Blast furnace, ferromanganese	92,400	107,300	¹ 140,400	¹ 143,400	140,000
Electric furnace, other ⁹	10,000	¹ 10,000	10,000	10,000	10,000
Total⁹	102,400	117,300	¹150,400	¹153,400	150,000
United States: Electric furnace:					
Ferromanganese ¹⁵	102,462	W	W	W	W
Ferrosilicon	324,097	449,328	475,256	433,726	⁴ 338,154
Silicon metal	135,559	149,094	136,531	140,792	⁴ 145,275
Ferrochromium ¹⁶	106,716	¹ 119,645	¹ 146,844	¹ 108,932	⁴ 68,327
Ferronickel	—	—	682	7,333	⁴ 14,251
Other	68,822	² 228,023	¹ 171,137	¹ 183,910	⁴ 211,266
Total	737,656	946,090	930,450	874,693	⁴777,273
Uruguay: Electric furnace, ferrosilicon ⁹	250	250	250	250	250
Venezuela: Electric furnace:					
Silicomanganese	28,000	33,760	³ 32,387	³ 30,000	30,000
Ferrosilicon	52,188	51,363	⁵ 54,873	⁵ 55,000	55,000
Total	80,188	85,123	⁸87,260	⁸85,000	85,000
Yugoslavia: Electric furnace:					
Ferromanganese	38,041	45,078	³ 33,868	³ 31,822	20,000
Silicomanganese	42,528	46,804	⁵ 52,588	⁶ 60,601	50,000
Ferrosilicon	98,843	120,522	¹ 122,179	¹ 103,188	70,000
Silicon metal	31,915	25,830	15,897	¹ 12,661	10,000
Ferrochromium	56,276	93,349	⁹ 90,428	⁸ 82,687	60,000

See footnotes at end of table.

TABLE 25—Continued
FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE¹

(Metric tons)

Country, furnace type, ² and alloy type ³	1987	1988	1989	1990	1991 [*]
Yugoslavia: Electric furnace—Continued:					
Ferromanganese-silicon	6,240	3,688	3,815	⁴ 4,199	3,000
Ferronickel	9,556	15,047	17,102	⁵ 11,850	7,000
Calcium-silicon	487	772	⁶ 144	⁷ 835	1,000
Other	7,584	10,678	⁸ 11,199	⁹ 10,462	9,000
Total	291,470	361,768	¹⁰347,220	¹¹318,305	230,000
Zimbabwe: Electric furnace:					
Ferromanganese	8,500	¹² 2,000	—	—	—
Ferromanganese	186,947	224,000	173,000	¹³ 225,102	200,000
Ferromanganese-silicon	21,000	29,000	25,000	¹⁴ 16,612	17,000
Total	216,447	¹⁵255,000	198,000	¹⁶241,714	217,000
Grand total	¹⁷17,683,109	¹⁸19,526,774	¹⁹20,056,606	²⁰19,410,001	18,490,703
Of which:					
Blast furnace:					
Spiegeleisen ¹⁷	21,991	19,329	18,906	17,140	15,140
Ferromanganese ^{17 18}	1,432,521	1,555,362	1,655,962	1,604,330	1,530,000
Ferrosilicon	40,000	65,000	75,000	120,000	125,000
Other	219,400	211,000	189,000	195,000	192,000
Total blast furnace	²¹1,713,912	²²1,850,691	²³1,938,868	²⁴1,936,470	1,862,140
Electric furnace:					
Ferromanganese ^{19 20}	²⁵ 2,942,643	²⁶ 3,205,030	²⁷ 3,113,938	²⁸ 3,168,914	2,758,047
Silicomanganese ¹⁹	²⁹ 2,770,663	³⁰ 2,812,681	³¹ 2,939,372	³² 2,817,965	2,616,013
Ferrosilicon	³³ 4,466,126	³⁴ 5,018,384	³⁵ 5,230,070	³⁶ 4,970,539	4,732,286
Silicon metal	³⁷ 551,661	³⁸ 613,851	³⁹ 618,401	⁴⁰ 630,168	586,877
Ferromanganese ²¹	⁴¹ 3,307,202	⁴² 3,714,834	⁴³ 4,067,471	⁴⁴ 3,521,600	3,464,638
Ferromanganese-silicon	⁴⁵ 61,140	⁴⁶ 58,634	⁴⁷ 63,137	⁴⁸ 46,784	38,524
Ferronickel	625,241	719,940	768,194	694,876	751,454
Other	⁴⁹ 1,244,521	⁵⁰ 1,532,729	⁵¹ 1,317,155	⁵² 1,622,685	1,680,724
Total electric furnace	⁵³15,969,197	⁵⁴17,676,083	⁵⁵18,117,738	⁵⁶17,473,531	16,628,563

^{*}Estimated. [†]Revised. NA Not available. W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Table includes data available through May 29, 1992.

²To the extent possible, ferroalloy production of each country has been separated according to the furnace type from which production is obtained; production derived from metallothermic operations is included with electric furnace production.

³To the extent possible, ferroalloy production of each country has been separated so as to show individually the following major types of ferroalloys: Spiegeleisen, ferromanganese, silicomanganese, ferrosilicon, silicon metal, ferromanganese, ferromanganese-silicon, and ferronickel. Ferroalloys other than those listed that have been identified specifically in sources, as well as ferroalloys not identified specifically have been reported as "Other." For countries for which one or more of the individual ferroalloys listed separately in this footnote have been inseparable from some other ferroalloys owing to the nation's reporting system, such deviations are indicated by individual footnotes.

⁴Reported figure.

⁵Includes silicomanganese.

⁶Included with other.

⁷Includes ferromanganese-silicon and ferronickel, if any was produced.

⁸Includes silicospiegeleisen.

⁹Includes ferronickel, if any was produced.

¹⁰Series excludes calcium silicide.

¹¹Includes calcium-silicon, ferrotungsten, ferromolybdenum, ferromanganese, ferrocolumbium, and other ferroalloys.

¹²Estimated figures based on reported exports and an allowance for domestic use.

¹³Includes production from Bophuthatswana. Includes net production of ferromanganese-silicon, if there was any.

¹⁴Soviet production of electric furnace ferroalloys is not reported; estimates provided are based on crude source material production and availability for consumption (including estimates) and upon reported ferroalloy trade, including data from trading partner countries.

¹⁵U.S. output of ferromanganese includes silicomanganese and manganese metal.

¹⁶U.S. output of ferromanganese includes high- and low-carbon ferromanganese, ferromanganese-silicon, chromium metal, and other chromium materials.

¹⁷Spiegeleisen for the Western states of Germany is included with blast furnace ferromanganese.

¹⁸Includes silicospiegeleisen for France.

¹⁹Ferromanganese includes silicomanganese (if any was produced) for countries carrying footnote 5 on "Ferromanganese" data line.

²⁰U.S. production under "Other" for 1988-91.

²¹Ferromanganese includes ferromanganese-silicon (if any was produced) for Republic of South Africa and United States.

IRON AND STEEL SCRAP

By Raymond E. Brown

Mr. Brown, a physical scientist with 36 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for iron and steel scrap since 1986. Domestic survey data were prepared by Robert W. Thompson and Henry F. Sattlighthigh, Ferrous Data Section. International data tables were prepared by William L. Zajac, Chief, International Data Section.

Use of iron and steel scrap to produce new steel and ferrous castings, vital to the United States for both national security and economic well-being, represented significant energy, environmental, economic, and resource conservation benefits. Direct-reduced iron, pig iron, and iron carbide could be substituted for iron and steel scrap but were usually considered more expensive than scrap. Also, availability of these substitutes on a large scale was limited, and there were certain technical problems associated with the use of some of these substitute materials. However, these scrap alternatives had certain advantages, which included providing iron free of residual elements, such as copper, for use in producing higher quality steel and ferrous castings products.

The metric system is the official system of measurement of most countries. The U.S. Bureau of Mines, in an effort to provide statistical data on iron and steel scrap that are consistent with international usage, has reported data in kilograms and metric tons unless otherwise noted. To convert from: short tons (st) to metric tons (mt) multiply by 0.907185; long tons (lt) to metric tons multiply by 1.016047; metric tons to short tons multiply by 1.102312; metric tons to long tons multiply by 0.984207; metric tons to kilograms (kg) multiply by 1,000; and kilograms to metric tons multiply by 0.001. The number of pounds (lb), avoirdupois, in a: short ton or net ton (nt) = 2,000; long ton or gross ton (gt) = 2,240; metric ton =

2,204.623; and kilogram = 2.204623. All tables, except for table 16, which reported the selling price of No. 1 heavy melting steel scrap in dollars per long ton as well as dollars per metric ton, and the text of this publication employed the metric system.

Brokers, dealers, and other outside sources supplied domestic consumers in 1991 with 40.7 million metric tons¹ of all types of ferrous scrap at a delivered value of approximately \$4.15 billion, while exporting 9.3 million tons (excluding used rails for rerolling and other uses; and ships, boats, and other vessels for scrapping) valued at \$1.23 billion. In 1990, domestic consumers received 45.6 million tons at a delivered value of approximately \$5.32 billion; exports totaled 11.6 million tons valued at \$1.64 billion. This represented tonnage decreases of 11% for received quantities and 19% for exported quantities.

DOMESTIC DATA COVERAGE

Domestic production data for ferrous scrap were developed by the U.S. Bureau of Mines from voluntary monthly or annual surveys of U.S. operations. Of the operations to which a survey request was sent, 58% responded, representing an estimated 73% of the total consumption shown in table 2 for three types of scrap consumers. Consumption for the nonrespondents was estimated using prior reports adjusted by industry trends. An estimation error was also contained in the difference between the reported total

consumption of purchased and home scrap and the sum of scrap receipts plus home scrap production, less scrap shipments and adjustments for stock changes. For scrap consumption data shown in table 2, this difference amounted to 0.2% for manufacturers of pig iron and raw steel and castings, 3% for manufacturers of steel castings, 5% for iron foundries and miscellaneous users, and 1% average for all types of manufacturers combined. (See table 1.)

ANNUAL REVIEW

Legislation and Government Programs

The Environmental Protection Agency (EPA) conducted a pilot study to investigate the presence of polychlorinated biphenyls (PCB's) and other hazardous substances in waste products produced at metal salvage and recycling facilities. Input materials were segregated by type to allow separate shredding of three distinct material categories: automobiles only, white goods (appliances) only, and mixed input. PCB's were found in all sampled materials. However, 98% of the PCB's was associated with the shredder residue waste product, which is better known as fluff. Lead and cadmium were also found in most of the fluff samples.²

The EPA proposed treatment standards under the land disposal restrictions program for electric arc furnace (EAF) dust (wastes identified as K061 dust) that were nonwastewaters and contained 15%

or more total zinc.³ The Institute of Scrap Recycling Industries, Inc. (ISRI) had asked the EPA to remove metal shredders and recyclers from the list of categories potentially subject to emission standards under section 112 of the Clean Air Act.⁴ The EPA would target metal-related toxics and their producers among "strategic initiatives" under the President's \$6.2 billion EPA budget proposal for 1992.⁵

Bethlehem Steel Corp. and the U.S. Department of Energy signed an agreement for the engineering, construction, and operation of a blast furnace coal injection demonstration project at Bethlehem's Burns Harbor, IN, plant. Total cost of the project was \$144 million. Its aim was to inject granulated coal directly into the blast furnace combustion zone.⁶

Environmental and other legislation that the U.S. Congress was considering action on included the following: the Resource Conservation and Recovery Act (RCRA), the Nation's primary recycling and disposal statute, which defined what was waste and determined which wastes were hazardous; the Comprehensive Environmental Response and Cleanup Liability Act (CERCLA or Superfund), which held scrap processors and recyclers liable for environmental cleanup; limiting trade of "wastes" across State and international boundaries; the Toxic Substances Control Act (TSCA), which governed the use of toxic materials in manufactured articles, restricting their use when danger to the environment could be demonstrated; encouraging increased recycling; promoting markets for recycled goods; and increasing the duty on imported products containing U.S. processed scrap.

Available Supply, Consumption, and Stocks

Overall domestic demand for ferrous scrap in 1991 by the iron and steel and the ferrous castings industries, the major consumers of this raw material, was down about 12% compared with that of 1990. Because of weaker demand worldwide for ferrous scrap in 1991,

average annual prices for most scrap grades declined.

According to the Steel Can Recycling Institute (SCRI), Pittsburgh, PA, new and expanded steel can recycling programs throughout the United States pushed the 1991 overall recycling rate for certain types of steel cans to a record high of 34%. The 1991 figure represented a 38% increase compared with the 1990 overall recycling rate of 24.6% for food and beverage cans. In addition to food and beverage cans, SCRI included in its 1991 calculations paint and aerosol cans plus lids and closures found on other containers. About 880,000 metric tons of used steel cans was recycled into new steel and iron products or used in the copper precipitation industry in 1991.

Proler International Corp., a major processor of ferrous and nonferrous scrap, shut down its year-old detinning plant in Houston, TX, after losing \$3 million on its operations in 1990. The detinning plant, which came on-stream in May 1990 and was the largest in the United States, suffered from competition from its main customers, domestic steel mills, and the lack of future business from a proposed but unsuccessful new minimill plant called Buffalo Steel.⁷

Three communities in Indianapolis, IN, Lawrenceville, GA, and San Antonio, TX, were selected as winners in the 1991 Steel Recycling Award. The award, jointly sponsored by Keep America Beautiful, Inc., Stamford, CT, the Steel Can Recycling Institute, Pittsburgh, PA, and the American Iron and Steel Institute, Washington, DC, was open to more than 460 certified and precertified Keep America Beautiful Inc. affiliate communities. The three winners, selected for their efforts in helping communities develop innovative educational programs and sustaining the recycling of steel, aluminum, glass and plastic containers and paper, each received cash awards.

Nucor Corp., headquartered in Charlotte, NC, was building a new flat-rolled steel facility in Hickman, AR. This \$300 million mill, with an annual capacity of more than 1 million tons, would be in operation by early 1993.

This was the second minimill facility to be built in the United States to employ thin-slab casting technology. Nucor's first flat-rolled steel plant, in Crawfordsville, IN, with an annual capacity of about 1 million tons per year, began production in June 1989. The Crawfordsville plant maintained total residual levels of less than 0.25% in furnace charges.⁸

The Erman-Howell division of Luria Steel and Trading Corp., a 66-year-old scrap brokerage firm headquartered in Bannockburn, IL, went to bankruptcy court in May to seek protection from its creditors. Erman-Howell intended to wind down its business and liquidate its assets under the voluntary chapter 11 petition filed in U.S. Bankruptcy Court in Chicago, IL.

A recycling consortium would be formed by the big three U.S. automakers, General Motors Corp., Ford Motor Co., and Chrysler Corp., to develop technology for recycling the 20% to 25% of a vehicle's weight that was not recovered and reused. The consortium also would be expected to try to develop improvements of existing techniques for handling recyclable materials and to develop or encourage component designs that expedite disassembly. Additionally, the group would be expected to work on improved, more acceptable methods of material disposal. German automaker BMW had also launched a pilot program in North America with a view of building a national recycling capacity for all BMW models once they had reached the end of their natural lives.⁹

Maytag Corp. would begin using plastic tubs in place of porcelain-enameled steel units in its dishwashers by the middle of 1992. This switch would cost the steel industry 5,000 tons or more of cold-rolled sheet annually. Executives and engineers at Whirlpool Corp. were considering the use of laminated steel in the drums of electric and gas dryers for the home laundry market in this country. Each drum was made from 12- to 13-pound blanks of cold-rolled steel, and appliance industry sources estimated Whirlpool used close to 14,000 tons of the metal each year for the drums.

Laminated metal could lower dryer operation noise levels. Laminated metallic materials, composed of two sheets of steel or aluminum with a layer of viscoelastic plastic placed between, formed a sandwich composed of metal-plastic-metal.

Geneva Steel, Provo, UT, shut down the last operating open-hearth furnace used for steelmaking in the United States in December 1991. The eight open-hearth furnaces that had been used by Geneva were replaced by two revamped basic oxygen process (Q-BOP) furnaces. Open-hearth steel production in the United States began in 1868. The open-hearth process reached its peak in 1955 when 90% of this country's steel was produced by this method. Since 1955, steel production by the open-hearth process had been replaced by the basic oxygen and the electric furnace processes.

Florida Steel Corp. began operating a new 60-ton direct current arc furnace at its steel mill in Tampa, FL. The furnace was built by Deutsche Voest-Alpine Industrieanlagenbau GmbH, Dusseldorf, Federal Republic of Germany, and is based on a concept jointly developed with Florida Steel.¹⁰

North Star Steel Co., headquartered in Minneapolis, MN, had shuttered indefinitely its Milton, PA, minimill facility, citing slow orders for rebar and an unexpected transformer failure. The company planned to conduct a study of east coast construction markets before restarting the plant. North Star was also studying the idea of building its first minimill plant west of the Rockies.

USX Corp. permanently closed the iron and steel-producing operations and a pipe mill at its Fairless Works in Fairless Hills, PA, in March 1991. U.S. steel broke ground for this massive open-hearth steelmaking plant, the largest steel mill ever built, in 1951. The plant, which opened in 1952, was a major consumer of ferrous scrap.

A U.S. Congressman, versed on environmental issues that impact the scrap processing industry, addressed the keynote breakfast at the ISRI convention in Las Vegas, NV, in March.¹¹ In

addition to traditional "spotlight" sessions on metals, the ISRI Convention provided an expanded consideration of nonmetallic commodities that included plastics recycling.

U.S. steelmakers continued their quest for higher quality flat-rolled products by investing hundreds of millions of dollars in modernization programs designed to lift product quality, enhance mill productivity, and satisfy the demands of increasingly finicky customers.¹²

Imports of metallurgical-grade coke increased 44% in 1991 to 997,000 tons compared with that of 1990. Metallurgical coke imports represented 5% of domestic apparent consumption in 1991 compared with 3% in 1990. The United States continued as a net importer of metallurgical coke. Domestic coal consumption in coke plants decreased 13% in 1991 to 30.7 million tons. Domestic metallurgical coal exports increased 2% in 1991 to 58.6 million tons compared with those of 1990.

Raw steel production was 79.7 million tons in 1991 compared with 89.7 million tons in 1990. The shares of raw steel produced by electric, basic oxygen, and open-hearth furnaces were, respectively, 38%, 60%, and 2% in 1991 and 37%, 59%, and 4% in 1990. Continuous cast steel production represented 76% of total raw steel production in 1991 compared with 67% in 1990. Raw steel capacity utilization was 75% in 1991 and 85% in 1990. Raw steel production capability was 106.7 million tons in 1991 compared with 105.9 million tons in 1990.

Net shipments of all grades of steel mill products were 71.5 million tons in 1991 and 77.1 million tons in 1990. Imports of steel mill products decreased from 15.6 million tons in 1990 to 14.4 million tons in 1991. Exports of steel mill products increased from 3.90 million tons in 1990 to 5.76 million tons in 1991. The apparent supply of steel mill products decreased from 88.8 million tons in 1990 to 80.1 million tons in 1991. Imports of steel mill products, as a share of the U.S. market, were 18% in both 1990 and 1991. Estimated steel mill processing yields [(total net shipments of steel mill products/total raw steel production)(100)]

increased from 86% in 1990 to 90% in 1991. Pig iron production decreased from 49.7 million tons in 1990 to 44.1 million tons in 1991.

Iron castings shipments totaled 6.74 million tons in 1991 compared with 7.76 million tons (revised) in 1990. Steel castings shipments (including investment castings) totaled 0.94 million tons in 1991 compared with 1.06 million tons (revised) in 1990.

Steel mills accounted for 76% of all scrap received from brokers, dealers, and other outside sources; steel foundries received 5%; and iron castings producers and miscellaneous users received 19%. The apparent total domestic consumption of ferrous scrap in 1991, in million tons, was composed of 39.8 net receipts (total receipts minus shipments), 21.5 home scrap, and 0.2 withdrawals from stocks. The 1991 total was 61.5 million tons; the apparent total domestic consumption was 69.5 million tons in 1990. The total market for U.S. scrap (net receipts plus exports minus imports) was 48.2 million tons in 1991 compared with 54.7 million tons (revised) in 1990. Stocks of ferrous scrap held by both steel mills and ferrous foundries decreased in 1991. (See figure 1.)

Prices

Based on average composite delivered prices per long ton quoted weekly and monthly by the American Metal Market (AMM), converted to metric tons, No. 1 heavy melting steel scrap cost \$91.79 in 1991, ranging from a low of \$84.32 in December to a high of \$103.38 in January. Based on Iron Age data, also converted to metric tons, No. 1 heavy melting steel scrap cost \$91.74 in 1991, ranging from \$83.88 in December to \$101.62 in January. The average composite price for No. 1 heavy melting steel scrap in 1991 was lower compared with that of 1990, by 13% based on both AMM and Iron Age data. Based on prices quoted weekly by Iron Age for tonnages of 18-8-grade stainless steel scrap (bundles and solids) delivered to consumers in the Pittsburgh, PA, area, the average price of nickel-bearing

stainless steel scrap decreased 6%, from \$911.62 per ton in 1990 to \$861.28 per ton in 1991.

In 1991, the average price for total ferrous scrap exports (excluding used rails for rerolling and other uses and ships, boats, and other vessels for scrapping) decreased 7% to \$131.92 per ton compared with that of 1990, while that of total imports increased 1% to \$132.81 per ton.

Foreign Trade

Foreign trade tables were based on the Harmonized Tariff Schedule (HTS), which became effective January 1, 1989. Additionally, valuation continued to be reported on an f.a.s. basis for exports and on a customs value basis for imports.

The trade surplus in 1991 for all classes of ferrous scrap (including used rails for rerolling and other uses and ships, boats, and other vessels for scrapping) was \$1.09 billion in value and 8.3 million tons in quantity. This represented a decrease of 25% in value and 18% in quantity compared with the 1990 surplus of \$1.46 billion (revised) in value and 10.2 million tons (revised) in quantity. The balance of trade for all U.S. merchandise [exports (f.a.s.) less imports (customs value)] showed a deficit of \$65.4 billion in 1991, down from a deficit of \$101.7 billion in 1990.

The quantity and value of total exports and imports in 1991 declined from the record highs of 1990. In 1991, the quantity of total imports decreased by a slightly larger percentage compared with the quantity of total exports. In contrast, the value in 1991 of total exports decreased by a larger percentage compared with that of imports.

Total U.S. exports of ferrous scrap (excluding used rails for rerolling and other uses; ships, boats, and other vessels for scrapping; stainless steel; and alloy steel) in 1991 went to 54 countries and totaled 8,851,187 tons valued at \$978,368,820 for an average of \$110.54 per ton. Six countries received 78% of the total quantity. The largest tonnages went to the Republic of Korea, 2,609,651 tons; Turkey, 1,776,487 tons; Taiwan,

778,184 tons; Canada, 714,783 tons; India, 591,664 tons; and Mexico, 492,502 tons. The value of scrap exports to these six countries was \$911,363,875, 69% of the total value.

Total U.S. exports of stainless steel scrap in 1991 went to 32 countries and consisted of 232,089 tons valued at \$196,379,504 averaging \$846.14 per ton. Six countries received 94% of the total quantity. The largest tonnages went to the Republic of Korea, 94,333 tons; Japan, 67,954 tons; Canada, 20,739 tons; Italy, 16,076 tons; Spain, 13,022 tons; and Taiwan, 4,979 tons. The value of stainless steel scrap exports to these six countries was \$182,899,411, 93% of the total value.

U.S. exports of alloy steel scrap (excluding stainless steel) in 1991 were shipped to 42 countries. The total comprised 261,868 tons valued at \$58,096,797, for an average of \$221.86 per ton. Six countries received 85% of the total quantity; the largest tonnages went to the Republic of Korea, 79,930 tons; Canada, 70,682 tons; Mexico, 23,219 tons; China, 19,125 tons; Taiwan, 16,976 tons; and Hong Kong, 12,794 tons. The value of alloy steel scrap to these six countries was \$46,056,605, 79% of the total value.

In 1991, based on tonnage of iron and steel scrap by customs district, New York, NY, was the leading customs district for exports, accounting for 18% of the total exports, followed by Los Angeles, CA, with 15%, and Philadelphia, PA, with 10%. Pembina, ND, was the leading customs district for reexports, accounting for 48% of the total reexports, followed by Detroit, MI, with 30%, and New York, NY, with 7%. Detroit, MI, was the leading customs district for imports, accounting for 36% of the total imports, followed by Seattle, WA, with 29%, and Buffalo, NY, with 8%. In 1990, again based on tonnage of ferrous scrap by customs district, New York, NY, was the leading customs district for exports, accounting for 17% of the total exports, followed by Los Angeles, CA, with 13%, and Philadelphia, PA, with 9%. San Juan, PR, was the leading customs district for

reexports, accounting for 42% of the total reexports, followed by Detroit, MI, with 36%, and Providence, RI, with 17%. Detroit, MI, was the leading customs district for imports, accounting for 43% of the total imports, followed by Seattle, WA, with 25%, and Buffalo, NY, with 8%. For more details, including tonnages and values, refer to published data in U.S. Bureau of Mines Mineral Industry Surveys on iron and steel scrap.¹³

Total U.S. imports for consumption of iron and steel scrap were supplied by 38 countries in 1991. They contained 10,109 tons of tinplate waste or scrap valued at \$2,240,032.

World Review

World demand for iron and steel scrap in 1991 was estimated to have decreased 4% compared with that of 1990. However, demand for ferrous scrap in 1991 increased in certain countries. These included industrialized countries such as Canada, the Federal Republic of Germany, and the Republic of South Africa; Asian countries such as China, India, Indonesia, the Republic of Korea, and Taiwan; Latin American countries such as Brazil and Venezuela; Middle Eastern countries such as Iran; and African countries such as Egypt.

The United States continued to be the leading exporting country of iron and steel scrap. France, the Federal Republic of Germany, the Netherlands, the U.S.S.R., and the United Kingdom were also major exporters of ferrous scrap.

In October 1991, the 7 nations of the European Free Trade Association (EFTA) and the 12 members of the European Community (EC) reached an agreement to link together Western Europe's 380 million people into a powerful new economic bloc. The agreement would create a European Economic Area, the world's largest and wealthiest single market, when it takes effect on January 1, 1993. The arrangement was reached among foreign ministers and trade ministers that met in Luxembourg after more than 1 year of often difficult negotiations and must be approved by the

Governments of all 19 countries. The deal would effectively expand the EC's single market. However, the sensitive sector of agriculture would be excluded.

Trade barriers at State and local levels emerged as a significant new problem for foreign companies seeking business in the United States, according to a new EC report. In addition, the report contended that while most countries were pushing vigorously toward a global trade system, the United States continued to rely heavily on unilateral actions to solve trade problems.¹⁴

Automotive recycling programs were active in Europe as well as in the United States. A joint venture on automobile recycling by Mercedes-Benz AG, Federal Republic of Germany, and Voest-Alpine AG, Austria, allowed car recycling with minimal environmental impact and without the need for removing plastics from the vehicles.¹⁵ An association of German companies, led by automaker Adam Opel AG, was working to produce cars that are 100% recyclable. Other group participants, including Hoesch AG, Thyssen AG, and Bayer AG, would provide expertise in steel, glass, and plastics. Draft laws that threaten to make automakers dispose of scrap vehicles prompted the search for an all-recyclable car.¹⁶ Mercedes-Benz AG and other German carmakers, including Volkswagen AG, had agreed to take back the autos they manufactured for recycling. Peugeot SA, a French automaker, had joined with two other organizations to launch a junk car recycling program that would process more than 7,000 vehicles over a 2-year period. In the Federal Republic of Germany, BMW AG and Volkswagen AG had started auto disassembly plants to recover metals, plastics, glass, and other materials from old vehicles.¹⁷

Governments in Belgium and Denmark had agreed to refund to scrap processors part of the cost of disposal of fluff generated from their shredder operations.¹⁸ The Federal Republic of Germany recently enacted tough laws aimed at reducing waste.¹⁹ SIDERINSA, the association of independent iron and steel producers in Madrid, Spain, signed

a contract with Tecnicas Reunidas (Madrid) for a project that would treat dust generated from Spanish steelworks.

Canadian scrap metal processors faced an ever-rising tide of Government regulations that were driving up the cost of business, according to the leader of the Canadian Association of Recycling Industries (CARI). According to a Canadian Federal environmental official, Canada's scrap processing industry was essential to that nation's goal of a 50% waste reduction by the end of this century.

Japan, which was importing ferrous scrap at an annual rate of more than 300,000 tons for the past 15 years, began turning into a ferrous scrap exporting country in 1991. Ferrous scrap exports from that country in December 1991 exceeded 200,000 tons. It was highly probable that total exports of ferrous scrap from Japan in 1991 would exceed 1 million tons. Two dramatic changes had occurred in the structure of the Japanese ferrous scrap market in the past 4 years. Namely, scrap imports declined sharply and pig iron imports rose significantly. Japan's next generation effort to streamline steelmaking, known as the direct iron ore smelting reduction process (DIOS), was said to be making good progress. A pilot plant was scheduled to open in 1993. Japan passed a new law that emphasized the recycling of natural resources. A new program to increase recycling of aluminum and steel cans was implemented.

Korean steelmaker Han Kook Steel and Mill Co. Ltd., Haman, Republic of Korea, had placed an order with ABB Metallurgy for the supply of a 50-ton direct current electric arc furnace. The furnace would feature a 35-megavolt-ampere transformer and was scheduled to go on-stream in the second quarter of 1992.

Thousands of pieces of excess U.S. military equipment and scrap metal left over from Operation Desert Storm would be auctioned off in Saudi Arabia. Items ranging from chairs and vehicles to ferrous and nonferrous scrap would be sold.

Independent steelmakers had expressed concern over falling quality standards in the United Kingdom's ferrous scrap supplies. In its annual report, the British Independent Steel Producers' Association (BISPA) stated that over the past year "most steel plants encountered an increasing incidence of scrap quality problems," including downgrading of material and scrap contamination.²⁰

Current Research

Florida Steel Corp. installed the Constee process at its Charlotte, NC, steel minimill in 1989. A feature of the process is the continuous charging of preheated ferrous scrap to an electric arc furnace. The Center for Materials Production, Pittsburgh, PA, completed an industry and utility-sponsored study of the process. The results of the analysis showed that Florida Steel had achieved productivity and electrode usage improvements, but energy usage had remained constant during the test period.²¹ Subsequent information indicated that Florida Steel had been able to achieve lower levels of energy consumption with further experience.

A technology to upgrade galvanized steel scrap into clean scrap for steelmaking had been unveiled by Metal Recovery Industries, Inc., U.S. (MRIUS), East Chicago, IN, and the U.S. Department of Energy's (DOE) Argonne National Laboratory, Argonne, IL. The technology uses an electrochemical process to dissolve the zinc coating off of galvanized steel surfaces. MRIUS planned to open a pilot facility in East Chicago, IN, by mid-1992. Metal Recovery Industries, Inc., Hamilton, Ontario, Canada, was the parent company of MRIUS.²²

OUTLOOK

The total market for U.S. ferrous scrap is affected by many factors. For example, major factors that impact the demand for domestic scrap include the quantities of domestic raw steel and ferrous castings produced, the level of scrap exports, and Government laws and

regulations. To a lesser extent, other factors affecting the overall market for U.S. scrap include the production levels of U.S. industries that make ferroalloys, cement copper, and certain chemicals; the use of scrap substitutes; technological changes in steel mills and ferrous foundries; and the value of the U.S. dollar in relation to other world currencies. The health of the world's steel mills and ferrous foundries is of the utmost importance to the domestic scrap industry. The United States, the world's leading exporter of ferrous scrap, relies heavily on exports as a safety valve for the release of excess scrap when domestic demand slips.

Although demand for ferrous scrap was down in 1991, the overall outlook for the total market for U.S. ferrous scrap through 1995 is expected to be one of continued growth. The total market for U.S. scrap is forecast to reach 64 million tons in 1995, which represents an average annual growth rate of about 2%. This optimistic forecast is based on a combination of favorable factors affecting the market, which include continued world growth in the quantity of steel produced in scrap-based electric arc furnaces; an increase in the percentage of steel that is continuously cast; and an absence of excessive Government rules or restrictions on U.S. exports of scrap.

¹All quantities are in metric tons unless otherwise specified.

²Reinhart, D., et al. Environmental Protection Agency (EPA). Project Summary: PCB, Lead, and Cadmium Levels in Shredder Waste Materials—A Pilot Study. EPA Report No.: 560/5-90-008A, Apr. 1991, 12 pp.

³Federal Register. Environmental Protection Agency. Proposed Rules; Land Disposal Restrictions for Electric Arc Furnace Dust (K061). V. 56, No. 71, Apr. 12, 1991, pp. 15020-15028.

⁴Recycling Manager. Legislative and Regulatory Roundup—Federal. Recycling Manager. V. 1, No. 16, Aug. 19, 1991, p. 4.

⁵Werber, M., and P. Abrahamson. EPA Budget Targets Toxics. Am. Met. Market, v. 99, No. 24, Feb. 6, 1991, pp. 1, 7.

⁶33 Metal Producing. Bethlehem, DOE Sign Agreement. V. 29, No. 4, Apr. 1991, p. 10.

⁷Metal Bulletin (London). Proler Shuts Detinning Plant. No. 7578, May 2, 1991, p. 15.

⁸Iverson, K. F. Progress at Minimills Will Come Fast. Am. Met. Market, v. 99, No. 147, Aug. 2, 1991, p. 14.

⁹Metal Bulletin (London). BMW in U.S. Recycling Venture. No. 7648, Jan. 16, 1992, p. 13.

¹⁰Steels Alert. Florida Steel Now Operating New DC Arc Furnace. V. 9, Nov. 1991, p. S-4.

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TABLE 1
SALIENT U.S. IRON AND STEEL SCRAP AND PIG IRON STATISTICS

(Thousand metric tons and thousand U.S. dollars)

Stocks, Dec. 31:	1987	1988	1989	1990	1991
Scrap at consumer plants	4,394	4,131	4,213	4,433	4,257
Pig iron at consumer and supplier plants	255	188	276	169	214
Total	4,649	4,319	4,489	4,602	4,472
Consumption:					
Scrap ²	61,963	69,692	65,507	70,451	62,020
Pig iron ³	45,386	53,567	52,968	51,100	45,810
Exports:					
Scrap	9,405	9,161	11,149	11,580	9,345
Value	967,018	1,351,955	1,748,643	1,635,218	1,232,845
Imports for consumption:					
Scrap (includes tinplate and terneplate) ⁴	765	942	1,016	1,309	1,073
Value	82,016	133,577	149,109	171,510	142,552

¹Revised.

²Data do not add to total shown because of independent rounding.

³Internal evaluation indicates that scrap consumption by manufacturers of pig iron and raw steel and castings is understated by the following approximated quantities: 4.1 million metric tons in electric furnaces in 1987; 4.7 million metric tons in electric furnaces and 0.2 million metric tons in open-hearth furnaces in 1988; 6.6 million metric tons in electric furnaces and 0.9 million metric tons in open-hearth furnaces in 1989; 2.9 million metric tons in electric furnaces in 1990; and 3.1 million metric tons in electric furnaces in 1991.

⁴Internal evaluation indicates that pig iron consumption (for open-hearth furnaces) is understated by approximately 1.5 million metric tons in 1988 and 0.8 million metric tons in 1989.

⁵Excludes used rails for rerolling and other uses and ships, boats, and other vessels for scrapping.

TABLE 2
U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS
OF IRON AND STEEL SCRAP IN 1991, BY GRADE

(Thousand metric tons)

Grade	Receipts of scrap		Production of home scrap		Consumption of both purchased and home scrap (includes recirculating scrap)	Shipments of scrap	Ending stocks, Dec. 31
	From brokers, dealers and other outside sources	From other own-company plants	Recirculating scrap from current operations	Obsolete scrap (includes ingot molds, stools, and other scrap from old equipment, buildings, etc.)			
MANUFACTURERS OF PIG IRON AND RAW STEEL AND CASTINGS							
Carbon steel:							
Low-phosphorus plate and punchings	471	—	3	—	459	—	38
Cut structural and plate	1,743	107	382	13	2,226	55	140
No. 1 heavy melting steel	6,531	218	6,400	419	11,551	2,001	805
No. 2 heavy melting steel	3,574	150	624	2	4,522	8	318
No. 1 and electric-furnace bundles	4,661	236	733	2	4,993	623	535
No. 2 and all other bundles	1,064	29	75	—	1,162	(¹)	57
Electric furnace, 1 foot and under (not bundles)	12	215	(¹)	—	229	—	9
Railroad rails	284	17	23	2	338	2	30
Turnings and borings	1,030	5	126	—	1,162	8	66
Slag scrap (Fe content 70%)	1,028	220	1,764	1	2,568	427	113
Shredded or fragmented	4,375	981	90	—	5,372	—	355
No. 1 busheling	1,620	125	98	—	1,764	35	140
All other carbon steel scrap	3,047	206	3,715	26	6,123	785	274
Stainless steel scrap	510	19	392	—	916	13	54
Alloy steel (except stainless)	105	104	543	(¹)	701	12	109
Ingot mold and stool scrap	93	97	206	274	502	177	127
Machinery and cupola cast iron	—	(¹)	4	—	1	2	1
Cast-iron borings	128	(¹)	(¹)	(¹)	115	4	11
Motor blocks	—	—	—	—	—	—	—
Other iron scrap	192	37	453	1	447	262	72
Other mixed scrap	419	140	95	(¹)	633	17	86
Total²	30,886	2,905	15,725	740	345,784	4,431	3,340

MANUFACTURERS OF STEEL CASTINGS

Carbon steel:							
Low-phosphorus plate and punchings	529	(¹)	129	(¹)	681	(¹)	35
Cut structural and plate	326	12	54	(¹)	390	4	36
No. 1 heavy melting steel	98	—	74	1	162	—	11
No. 2 heavy melting steel	135	—	2	—	142	—	8
No. 1 and electric-furnace bundles	9	—	—	—	8	—	1
No. 2 and all other bundles	—	—	—	—	—	—	—
Electric furnace, 1 foot and under (not bundles)	58	9	—	—	67	—	5
Railroad rails	66	—	1	—	66	—	2

See footnotes at end of table.

TABLE 2—Continued
**U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS
 OF IRON AND STEEL SCRAP IN 1991, BY GRADE**

(Thousand metric tons)

Grade	Receipts of scrap		Production of home scrap		Consumption of both purchased and home scrap (includes recirculating scrap)	Shipments of scrap	Ending stocks, Dec. 31
	From brokers, dealers and other outside sources	From other own-company plants	Recirculating scrap from current operations	Obsolete scrap (includes ingot molds, stools, and other scrap from old equipment, buildings, etc.)			
MANUFACTURERS OF STEEL CASTINGS—Continued							
Carbon steel—Continued							
Turnings and borings	19	—	17	—	30	4	3
Slag scrap (Fe content 70%)	—	—	—	—	—	—	—
Shredded or fragmentized	57	—	—	—	56	—	1
No. 1 busheling	63	—	—	—	6	—	4
All other carbon steel scrap	299	—	259	2	552	—	24
Stainless steel scrap	28	1	30	—	66	(¹)	10
Alloy steel (except stainless)	79	—	142	—	208	4	55
Ingot mold and stool scrap	—	—	—	—	—	—	—
Machinery and cupola cast iron	189	(¹)	38	—	243	—	6
Cast-iron borings	66	—	16	—	57	—	4
Motor blocks	—	—	—	—	(¹)	—	—
Other iron scrap	25	2	50	—	70	6	10
Other mixed scrap	—	—	10	—	10	—	(¹)
Total²	2,047	24	820	4	2,871	18	214
IRON FOUNDRIES AND MISCELLANEOUS CASTERS							
Carbon steel:							
Low-phosphorus plate and punchings	1,077	32	116	16	1,248	—	56
Cut structural and plate	919	14	81	—	1,037	(¹)	48
No. 1 heavy melting steel	117	98	105	—	313	5	30
No. 2 heavy melting steel	154	(¹)	246	—	226	182	4
No. 1 and electric-furnace bundles	97	177	13	—	287	—	5
No. 2 and all other bundles	143	—	1	—	146	—	21
Electric furnace, 1 foot and under (not bundles)	50	5	8	—	60	—	2
Railroad rails	226	—	2	—	224	2	13
Turnings and borings	349	38	5	—	385	2	41
Slag scrap (Fe content 70%)	42	—	4	—	42	4	2
Shredded or fragmentized	935	38	—	—	1,609	—	43
No. 1 busheling	419	94	15	—	578	—	15
All other carbon steel scrap	489	6	11	—	509	(¹)	65
Stainless steel scrap	7	—	11	—	17	(¹)	4
Alloy steel (except stainless)	22	—	9	—	31	(¹)	13

See footnotes at end of table.

TABLE 2—Continued
**U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS
 OF IRON AND STEEL SCRAP IN 1991, BY GRADE**

(Thousand metric tons)

Grade	Receipts of scrap		Production of home scrap		Consumption of both purchased and home scrap (includes recirculating scrap)	Shipments of scrap	Ending stocks, Dec. 31
	From brokers, dealers and other outside sources	From other own-company plants	Recirculating scrap from current operations	Obsolete scrap (includes ingot molds, stools, and other scrap from old equipment, buildings, etc.)			
IRON FOUNDRIES AND MISCELLANEOUS CASTERS—Continued							
Ingot mold and steel scrap	197	21	138	1	353	(¹)	27
Machinery and cupola cast iron	965	204	269	26	1,468	3	131
Cast-iron borings	400	91	71	—	554	7	37
Motor blocks	317	45	509	—	872	11	31
Other iron scrap	501	14	2,114	1	2,627	7	72
Other mixed scrap	343	11	395	1	778	14	46
Total²	7,769	890	4,121	45	13,364	238	703
TOTAL—ALL TYPES OF MANUFACTURERS							
Carbon steel:							
Low-phosphorus plate and punchings	2,076	32	247	16	2,388	—	129
Cut structural and plate	2,989	134	516	13	3,653	59	223
No. 1 heavy melting steel	6,745	315	6,580	419	12,026	2,006	847
No. 2 heavy melting steel	3,863	150	872	2	4,891	190	330
No. 1 and electric-furnace bundles	4,768	412	746	2	5,288	623	541
No. 2 and all other bundles	1,207	29	76	—	1,308	—	78
Electric furnace, 1 foot and under (not bundles)	121	229	8	—	356	—	16
Railroad rails	575	17	26	2	628	4	44
Turnings and borings	1,398	43	148	—	1,577	14	109
Slag scrap (Fe content 70%)	1,069	220	1,768	1	2,611	431	115
Shredded or fragmented	5,367	1,019	90	—	7,036	—	398
No. 1 busheling	2,103	218	113	—	2,405	35	159
All other carbon steel scrap	3,835	211	3,985	29	7,184	785	362
Stainless steel scrap	544	20	433	—	999	13	67
Alloy steel (except stainless)	206	104	694	—	940	17	178
Ingot mold and steel scrap	290	118	343	275	855	177	154
Machinery and cupola cast iron	1,155	204	311	26	1,711	4	138
Cast-iron borings	594	91	87	—	727	11	53
Motor blocks	317	45	509	—	872	11	31
Other iron scrap	718	53	2,617	2	3,144	275	154
Other mixed scrap	762	151	500	1	1,421	31	131
Total²	40,702	3,819	20,667	789	62,020	4,687	4,257

¹Less than 1/2 unit.

²Data may not add to totals shown because of independent rounding.

³Internal evaluation reveals that scrap consumption in electric furnaces operated by manufacturers of pig iron and raw steel and castings is understated by approximately 3.1 million metric tons.

TABLE 3
U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS
OF IRON AND STEEL SCRAP IN 1990, BY GRADE¹

(Thousand metric tons)

Grade	Receipts of scrap		Production of home scrap		Consumption of both purchased and home scrap (includes recirculating scrap)	Shipments of scrap	Ending stocks, Dec. 31
	From brokers, dealers and other outside sources	From other own-company plants	Recirculating scrap from current operations	Obsolete scrap (includes ingot molds, stools, and other scrap from old equipment, buildings, etc.)			
MANUFACTURERS OF PIG IRON AND RAW STEEL AND CASTINGS							
Carbon steel:							
Low-phosphorus plate and punchings	646	26	546	—	1,222	7	71
Cut structural and plate	1,966	138	491	30	2,563	24	173
No. 1 heavy melting steel	7,382	237	7,690	319	13,323	2,219	845
No. 2 heavy melting steel	4,324	168	810	2	5,281	10	354
No. 1 and electric-furnace bundles	5,586	168	896	7	6,027	637	517
No. 2 and all other bundles	1,132	29	120	—	1,243	43	58
Electric furnace, 1 foot and under (not bundles)	14	217	(^o)	—	230	—	11
Railroad rails	223	17	22	—	262	1	14
Turnings and borings	1,138	4	138	—	1,243	15	82
Slag scrap (Fe content 70%)	1,007	309	1,945	1	2,799	496	98
Shredded or fragmented	4,101	1,116	90	—	5,308	4	338
No. 1 busheling	1,805	137	123	(^o)	1,984	57	115
All other carbon steel scrap	3,554	150	3,968	85	6,826	942	283
Stainless steel scrap	527	20	403	—	942	15	41
Alloy steel (except stainless)	93	131	605	—	794	16	94
Ingot mold and steel scrap	84	71	260	360	574	226	131
Machinery and cupola cast iron	—	—	4	—	2	7	(^o)
Cast-iron borings	96	1	1	(^o)	84	13	6
Motor blocks	—	—	—	—	—	—	—
Other iron scrap	234	40	415	10	494	243	79
Other mixed scrap	549	85	89	(^o)	719	25	58
Total²	34,462	3,066	18,617	815	451,919	4,998	3,369
MANUFACTURERS OF STEEL CASTINGS							
Carbon steel:							
Low-phosphorus plate and punchings	549	22	96	(^o)	682	—	38
Cut structural and plate	404	13	75	(^o)	488	4	46
No. 1 heavy melting steel	188	—	83	—	240	1	26
No. 2 heavy melting steel	135	—	2	—	142	—	8
No. 1 and electric-furnace bundles	7	—	—	—	10	—	(^o)
No. 2 and all other bundles	—	—	—	—	—	—	—
Electric furnace, 1 foot and under (not bundles)	57	—	8	—	67	—	5
Railroad rails	32	—	—	—	32	—	2

See footnotes at end of table.

TABLE 3—Continued
**U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS
 OF IRON AND STEEL SCRAP IN 1990, BY GRADE¹**

(Thousand metric tons)

Grade	Receipts of scrap		Production of home scrap		Consumption of both purchased and home scrap (includes recirculating scrap)	Shipments of scrap	Ending stocks, Dec. 31
	From brokers, dealers and other outside sources	From other own-company plants	Recirculating scrap from current operations	Obsolete scrap (includes ingot molds, stools, and other scrap from old equipment, buildings, etc.)			
MANUFACTURERS OF STEEL CASTINGS—Continued							
Carbon steel—Continued:							
Turnings and borings	21	—	15	—	34	4	4
Slag scrap (Fe content 70%)	—	—	—	—	—	—	—
Shredded or fragmented	53	—	2	—	52	—	(^o)
No. 1 busheling	79	—	—	—	74	—	12
All other carbon steel scrap	409	—	178	—	578	—	33
Stainless steel scrap	36	1	34	—	78	1	12
Alloy steel (except stainless)	93	2	179	—	267	5	78
Ingot mold and steel scrap	—	—	—	—	—	—	—
Machinery and cupola cast iron	40	—	11	—	49	—	13
Cast-iron borings	66	—	17	—	58	—	4
Motor blocks	(^o)	—	—	—	(^o)	—	—
Other iron scrap	26	—	66	—	83	2	13
Other mixed scrap	—	10	—	—	10	—	(^o)
Total²	2,196	48	766	1	2,945	15	293
IRON FOUNDRIES AND MISCELLANEOUS CASTERS							
Carbon steel:							
Low-phosphorus plate and punchings	1,109	33	146	38	1,325	—	66
Cut structural and plate	1,043	11	98	(^o)	1,159	1	62
No. 1 heavy melting steel	83	99	257	—	300	139	27
No. 2 heavy melting steel	165	—	126	—	230	70	5
No. 1 and electric-furnace bundles	181	198	52	—	430	—	5
No. 2 and all other bundles	191	—	—	—	170	—	23
Electric furnace, 1 foot and under (not bundles)	75	207	8	—	288	—	3
Railroad rails	249	—	2	—	259	2	14
Turnings and borings	401	1	18	—	422	3	37
Slag scrap (Fe content 70%)	31	—	1	—	31	1	2
Shredded or fragmented	1,090	56	—	—	1,790	—	50
No. 1 busheling	477	73	11	—	622	—	13
All other carbon steel scrap	655	5	42	2	734	1	62
Stainless steel scrap	8	—	5	—	15	(^o)	4
Alloy steel (except stainless)	24	—	10	—	35	(^o)	13

See footnotes at end of table.

TABLE 3—Continued
**U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS
 OF IRON AND STEEL SCRAP IN 1990, BY GRADE¹**

(Thousand metric tons)

Grade	Receipts of scrap		Production of home scrap		Consumption of both purchased and home scrap (includes recirculating scrap)	Shipments of scrap	Ending stocks, Dec. 31
	From brokers, dealers and other outside sources	From other own-company plants	Recirculating scrap from current operations	Obsolete scrap (includes ingot molds, stools, and other scrap from old equipment, buildings, etc.)			
IRON FOUNDRIES AND MISCELLANEOUS CASTERS—Continued							
Ingot mold and stool scrap	191	9	176	2	377	10	27
Machinery and cupola cast iron	1,021	204	386	26	1,627	24	125
Cast-iron borings	435	103	132	—	660	15	40
Motor blocks	430	48	625	—	1,110	15	42
Other iron scrap	597	27	2,515	1	3,076	71	93
Other mixed scrap	445	116	373	6	927	33	61
Total²	8,901	1,188	4,984	76	15,587	383	771
TOTAL—ALL TYPES OF MANUFACTURERS							
Carbon steel:							
Low-phosphorus plate and punchings	2,304	81	788	38	3,229	7	175
Cut structural and plate	3,413	161	664	30	4,210	28	281
No. 1 heavy melting steel	7,653	336	8,030	319	13,862	2,358	899
No. 2 heavy melting steel	4,624	168	938	2	5,654	80	367
No. 1 and electric-furnace bundles	5,774	366	947	7	6,467	637	523
No. 2 and all other bundles	1,323	29	120	—	1,413	43	81
Electric furnace, 1 foot and under (not bundles)	146	424	16	—	585	—	18
Railroad rails	504	17	24	—	553	3	29
Turnings and borings	1,560	5	170	—	1,699	22	123
Slag scrap (Fe content 70%)	1,038	309	1,946	1	2,830	497	100
Shredded or fragmentized	5,245	1,172	92	—	7,150	4	388
No. 1 busheling	2,361	209	134	—	2,681	57	140
All other carbon steel scrap	4,618	155	4,188	87	8,137	943	377
Stainless steel scrap	572	21	442	—	1,034	16	57
Alloy steel (except stainless)	210	132	794	—	1,096	20	184
Ingot mold and stool scrap	275	80	436	362	951	236	158
Machinery and cupola cast iron	1,061	204	401	26	1,678	31	138
Cast-iron borings	597	104	150	—	801	27	50
Motor blocks	430	48	625	—	1,110	15	42
Other iron scrap	857	68	2,996	11	3,653	315	185
Other mixed scrap	994	211	462	6	1,656	57	119
Total³	45,560	4,301	24,366	891	70,451	5,396	4,433

¹All data for 1990 have been revised.

²Less than 1/2 unit.

³Data may not add to totals shown because of independent rounding.

⁴Internal evaluation reveals that scrap consumption in electric furnaces operated by manufacturers of pig iron and raw steel and castings is understated by approximately 2.9 million metric tons.

TABLE 4
U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF PIG IRON AND DIRECT REDUCED IRON IN 1991

(Thousand metric tons)

	Receipts	Production	Consumption	Shipments	Stocks, Dec. 31
MANUFACTURERS OF PIG IRON AND RAW STEEL AND CASTINGS					
Pig iron	1,847	43,901	44,908	919	127
MANUFACTURERS OF STEEL CASTINGS					
Pig iron	23	—	20	1	6
IRON FOUNDRIES AND MISCELLANEOUS USERS					
Pig iron	986	—	883	37	82
TOTAL—ALL TYPES OF MANUFACTURERS					
Pig iron ¹	2,856	43,901	45,810	957	214
Direct reduced or prereduced iron	834	—	852	—	99

¹Data may not add to totals shown because of independent rounding.

TABLE 5
U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF PIG IRON AND DIRECT REDUCED IRON IN 1990¹

(Thousand metric tons)

	Receipts	Production	Consumption	Shipments	Stocks, Dec. 31
MANUFACTURERS OF PIG IRON AND RAW STEEL AND CASTINGS					
Pig iron	1,956	48,898	49,798	1,294	77
MANUFACTURERS OF STEEL CASTINGS					
Pig iron	25	—	25	1	5
IRON FOUNDRIES AND MISCELLANEOUS USERS					
Pig iron	1,349	—	1,278	41	87
TOTAL—ALL TYPES OF MANUFACTURERS					
Pig iron ²	3,331	48,898	51,100	1,336	169
Direct reduced or prereduced iron	673	—	654	9	89

¹All data for 1990 have been revised.

²Data may not add to totals shown because of independent rounding.

TABLE 6
CONSUMPTION OF IRON AND STEEL SCRAP AND PIG IRON IN THE UNITED STATES IN 1991, BY TYPE OF FURNACE OR OTHER USE

(Thousand metric tons)

	Manufacturers of pig iron and raw steel and castings		Manufacturers of steel castings		Iron foundries and miscellaneous users		Total all types ¹	
	Scrap	Pig iron	Scrap	Pig iron	Scrap	Pig iron	Scrap	Pig iron
Blast furnace ²	2,142	—	—	—	—	—	2,142	—
Basic oxygen process ³	13,320	43,761	—	—	—	—	13,320	43,761
Open-hearth furnace	548	997	—	—	—	—	548	997
Electric furnace	429,354	6	2,440	20	5,960	612	37,754	638
Cupola furnace	51	22	398	(⁴)	7,345	255	7,794	277
Other (including air furnace) ⁵	369	9	33	—	59	16	461	25
Direct castings ⁷	—	112	—	—	—	—	—	112
Total ¹	45,784	44,908	2,871	20	13,364	883	62,020	45,810

¹Data may not add to totals shown because of independent rounding.

²Includes consumption in blast furnaces producing pig iron.

³Includes scrap and pig iron processed in metallurgical blast cupolas and used in oxygen converters.

⁴Internal evaluation indicates that scrap consumption in electric furnaces operated by manufacturers of pig iron and raw steel and castings is understated by approximately 3.1 million metric tons.

⁵Less than 1/2 unit.

⁶Includes vacuum melting furnaces and miscellaneous uses.

⁷Includes ingot molds and stools.

TABLE 7
CONSUMPTION OF IRON AND STEEL SCRAP AND PIG IRON IN THE UNITED STATES IN 1990, BY TYPE OF FURNACE OR OTHER USE¹

(Thousand metric tons)

	Manufacturers of pig iron and raw steel and castings		Manufacturers of steel castings		Iron foundries and miscellaneous users		Total all types ²	
	Scrap	Pig iron	Scrap	Pig iron	Scrap	Pig iron	Scrap	Pig iron
Blast furnace ³	2,527	—	—	—	—	—	2,527	—
Basic oxygen process ⁴	14,713	47,307	—	—	—	—	14,713	47,307
Open-hearth furnace	1,344	2,072	—	—	—	—	1,344	2,072
Electric furnace	32,780	7	2,688	25	7,223	951	42,691	982
Cupola furnace	30	25	257	(⁵)	8,221	308	8,508	332
Other (including air furnace) ⁷	526	—	—	—	144	19	670	19
Direct castings ⁸	—	387	—	—	—	—	—	387
Total ²	51,919	49,798	2,945	25	15,587	1,278	70,451	51,100

¹All data for 1990 have been revised.

²Data may not add to totals shown because of independent rounding.

³Includes consumption in blast furnaces producing pig iron.

⁴Includes scrap and pig iron processed in metallurgical blast cupolas and used in oxygen converters.

⁵Internal evaluation indicates that scrap consumption in electric furnaces operated by manufacturers of pig iron and raw steel and castings is understated by approximately 2.9 million metric tons.

⁶Less than 1/2 unit.

⁷Includes vacuum melting furnaces and miscellaneous uses.

⁸Includes ingot molds and stools.

TABLE 8
PROPORTION OF IRON AND STEEL SCRAP AND PIG IRON USED IN
FURNACES IN THE UNITED STATES IN 1991

(Percent)

Type of furnace	Scrap	Pig iron
Basic oxygen process	23.3	76.7
Open-hearth furnace	35.4	64.6
Electric furnace	98.7	1.3
Cupola furnace	95.0	5.0
Other (including air furnace)	97.0	3.0

TABLE 9
PROPORTION OF IRON AND STEEL SCRAP AND PIG IRON USED IN
FURNACES¹ IN THE UNITED STATES IN 1990

(Percent)

Type of furnace	Scrap	Pig iron
Basic oxygen process	23.7	76.3
Open-hearth furnace	39.3	60.7
Electric furnace	99.7	.3
Cupola furnace	97.7	2.3
Other (including air furnace)	99.0	1.0

¹All data for 1990 have been revised.

TABLE 10
IRON AND STEEL SCRAP SUPPLY¹ AVAILABLE FOR CONSUMPTION IN 1991, BY REGION AND STATE

(Thousand metric tons)

Region and State	Receipts of scrap		Production of home scrap		Total new supply ³	Shipments of scrap ⁴	New supply available for consumption ⁵
	From brokers, dealers, and other outside sources	From other own company plants	Recirculating scrap resulting from current operations	Obsolete scrap ²			
New England and Middle Atlantic:							
Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island	2,025	35	233	4	2,297	29	2,268
Pennsylvania	4,795	199	2,377	52	7,422	455	6,967
Total³	6,819	234	2,610	56	9,719	484	9,235
North Central:							
Illinois	4,184	489	1,608	10	6,292	69	6,223
Indiana	4,068	439	6,032	83	10,621	2,896	7,725
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	3,081	182	1,191	1	4,457	(⁶)	4,456
Michigan	2,789	443	1,720	10	4,961	146	4,815
Ohio	5,002	601	2,302	524	8,429	736	7,693
Total³	19,125	2,155	12,852	628	34,760	3,847	30,912
South Atlantic:							
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	3,695	568	1,686	18	5,968	199	5,769
South Central:							
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	8,558	813	2,623	44	12,038	147	11,891
Mountain and Pacific:							
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	2,505	49	896	43	3,492	10	3,482
Grand total³	40,702	3,819	20,667	789	65,976	4,687	61,289

¹New supply available for consumption is a net figure computed by adding production to receipts and deducting scrap shipped during the year. The plus or minus difference in stock levels at the beginning and end of the year is not taken into consideration.

²Obsolete scrap includes ingot molds, stools and scrap from old equipment, buildings, etc.

³Data may not add to totals shown because of independent rounding.

⁴Includes scrap shipped, transferred, or otherwise disposed of during the year.

⁵Less than 1/2 unit.

TABLE 11
IRON AND STEEL SCRAP SUPPLY¹ AVAILABLE FOR CONSUMPTION IN 1990, BY REGION AND STATE²

(Thousand metric tons)

Region and State	Receipts of scrap		Production of home scrap		Total new supply ⁴	Shipments of scrap ²	New supply available for consumption ⁴
	From brokers, dealers, and other outside sources	From other company plants	Recirculating scrap resulting from current operations	Obsolete scrap ³			
New England and Middle Atlantic:							
Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island	2,252	33	322	4	2,611	31	2,580
Pennsylvania	5,284	305	3,632	69	9,290	662	8,628
Total⁴	7,536	339	3,954	72	11,901	693	11,208
North Central:							
Illinois	4,367	695	1,981	11	7,055	94	6,961
Indiana	4,700	590	6,859	95	12,245	3,150	9,094
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	3,203	222	1,273	(*)	4,698	1	4,697
Michigan	3,220	402	1,834	12	5,468	152	5,316
Ohio	6,506	455	2,808	583	10,352	819	9,533
Total⁴	21,996	2,363	14,756	702	39,817	4,216	35,601
South Atlantic:							
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	4,301	590	1,948	21	6,860	277	6,583
South Central:							
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	8,693	960	2,550	50	12,253	207	12,046
Mountain and Pacific:							
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	3,034	49	1,158	46	4,288	4	4,285
Grand total⁴	45,560	4,301	24,366	892	75,119	5,396	69,723

¹New supply available for consumption is a net figure computed by adding production to receipts and deducting scrap shipped during the year. The plus or minus difference in stock levels at the beginning and end of the year is not taken into consideration.

²All data for 1990 have been revised.

³Obsolete scrap includes ingot molds, stools and scrap from old equipment, buildings, etc.

⁴Data may not add to totals shown because of independent rounding.

⁵Includes scrap shipped, transferred, or otherwise disposed of during the year.

⁶Less than 1/2 unit.

TABLE 12
U.S. CONSUMPTION OF IRON AND STEEL SCRAP AND PIG IRON¹ IN 1991, BY REGION AND STATE

(Thousand metric tons)

Region and State	Pig iron and steel ingots and castings		Steel castings		Iron foundries and miscellaneous users		Total ²	
	Scrap	Pig iron	Scrap	Pig iron	Scrap	Pig iron	Scrap	Pig iron
New England and Middle Atlantic:								
Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island	1,603	2	48	(³)	626	39	2,277	41
Pennsylvania	5,757	3,219	205	3	936	322	6,899	3,544
Total²	7,361	3,221	253	4	1,562	361	9,176	3,585
North Central:								
Illinois	4,722	2,467	189	—	1,338	55	6,249	2,523
Indiana	6,625	15,736	278	4	875	85	7,778	15,825
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	1,999	—	415	3	2,158	109	4,572	113
Michigan	2,314	4,691	6	(³)	2,567	109	4,887	4,800
Ohio	6,000	9,428	392	8	1,218	64	7,610	9,499
Total²	21,660	32,321	1,279	15	8,156	422	31,096	32,759
South Atlantic:								
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	4,889	4,336	15	(³)	927	27	5,831	4,363
South Central:								
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	9,259	3,708	698	(³)	1,885	66	11,842	3,774
Mountain and Pacific:								
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	2,615	1,321	626	1	833	7	4,074	1,329
Grand total²	45,784	44,908	2,871	20	13,364	883	62,020	45,810

¹Includes molten pig iron used for ingot molds and direct castings.

²Data may not add to totals shown because of independent rounding.

³Less than 1/2 unit.

⁴Internal evaluation indicates that scrap consumption in electric furnaces operated by manufacturers of pig iron and raw steel and castings is understated by approximately 3.1 million metric tons.

TABLE 13
U.S. CONSUMPTION OF IRON AND STEEL SCRAP AND PIG IRON¹ IN 1990, BY REGION AND STATE²

(Thousand metric tons)

Region and State	Pig iron and steel ingots and castings		Steel castings		Iron foundries and miscellaneous users		Total ³	
	Scrap	Pig iron	Scrap	Pig iron	Scrap	Pig iron	Scrap	Pig iron
New England and Middle Atlantic:								
Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island	1,768	3	54	(⁴)	783	72	2,604	76
Pennsylvania	7,193	4,572	183	4	1,241	528	8,617	5,104
Total³	8,961	4,575	237	4	2,023	601	11,221	5,180
North Central:								
Illinois	5,216	2,552	189	—	1,575	76	6,981	2,628
Indiana	7,847	17,188	357	4	880	85	9,085	17,278
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	1,911	(⁴)	412	4	2,375	129	4,698	133
Michigan	2,906	5,341	26	—	2,544	140	5,476	5,480
Ohio	7,229	10,274	420	9	1,907	145	9,556	10,428
Total³	25,109	35,356	1,404	18	9,282	574	35,795	35,948
South Atlantic:								
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	5,437	4,591	13	(⁴)	1,097	29	6,546	4,620
South Central:								
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	9,197	3,831	580	1	2,196	59	11,973	3,891
Mountain and Pacific:								
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	3,216	1,445	712	1	989	15	4,917	1,460
Grand total³	51,919	49,798	2,945	25	15,587	1,278	70,451	51,100

¹Includes molten pig iron used for ingot molds and direct castings.

²All data for 1990 have been revised.

³Data may not add to totals shown because of independent rounding.

⁴Less than 1/2 unit.

⁵Internal evaluation indicates that scrap consumption in electric furnaces operated by manufacturers of pig iron and raw steel and castings is understated by approximately 2.9 million metric tons.

TABLE 14
U.S. CONSUMER STOCKS OF IRON AND STEEL SCRAP AND PIG IRON, DECEMBER 31, 1991, BY REGION AND STATE

(Thousand metric tons)

	Carbon steel ¹	Stainless steel	Alloy steel ²	Cast iron ³	Other grades of	Total scrap	Pig iron stocks
New England and Middle Atlantic:							
Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island	84	4	50	36	8	183	18
Pennsylvania	391	43	59	84	4	581	16
Total⁴	<u>475</u>	<u>47</u>	<u>109</u>	<u>120</u>	<u>13</u>	<u>764</u>	<u>34</u>
North Central:							
Illinois	277	—	15	37	13	343	11
Indiana	459	2	3	79	16	559	82
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	206	3	3	25	17	255	25
Michigan	141	(⁵)	4	38	7	190	8
Ohio	508	11	29	73	1	624	20
Total⁴	<u>1,591</u>	<u>17</u>	<u>55</u>	<u>252</u>	<u>55</u>	<u>1,971</u>	<u>145</u>
South Atlantic:							
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	347	2	1	62	8	421	8
South Central:							
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	769	(⁵)	6	81	10	866	25
Mountain and Pacific:							
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	168	1	5	15	45	235	2
Grand total⁴	<u>3,351</u>	<u>67</u>	<u>178</u>	<u>530</u>	<u>131</u>	<u>4,257</u>	<u>214</u>

¹Excludes reolling rails.

²Excludes stainless steel.

³Includes borings.

⁴Data may not add to totals shown because of independent rounding.

⁵Less than 1/2 unit.

TABLE 15
U.S. CONSUMER STOCKS OF IRON AND STEEL SCRAP AND PIG IRON, DECEMBER 31, 1990, BY REGION AND STATE¹

(Thousand metric tons)

Region and State	Carbon steel ²	Stainless steel	Alloy steel ³	Cast iron ⁴	Other grades of scrap	Total scrap stocks ⁵	Pig iron stocks
New England and Middle Atlantic:							
Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island	93	4	51	33	7	188	19
Pennsylvania	394	30	57	86	10	577	11
Total	<u>487</u>	<u>34</u>	<u>108</u>	<u>119</u>	<u>17</u>	<u>765</u>	<u>30</u>
North Central:							
Illinois	344	—	11	40	7	403	10
Indiana	531	2	3	89	4	628	41
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	185	3	2	27	27	244	20
Michigan	144	2	4	48	9	206	10
Ohio	461	10	28	77	1	577	18
Total	<u>1,665</u>	<u>17</u>	<u>48</u>	<u>281</u>	<u>48</u>	<u>2,058</u>	<u>99</u>
South Atlantic:							
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	387	4	1	61	9	462	14
South Central:							
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	760	(6)	10	84	14	869	24
Mountain and Pacific:							
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	200	1	17	28	32	279	2
Grand total⁵	<u>3,500</u>	<u>56</u>	<u>184</u>	<u>573</u>	<u>119</u>	<u>4,433</u>	<u>169</u>

¹All data for 1990 have been revised.

²Excludes rerolling rails.

³Excludes stainless steel.

⁴Includes borings.

⁵Data may not add to totals shown because of independent rounding.

⁶Less than 1/2 unit.

TABLE 16
U.S. AVERAGE MONTHLY PRICE AND COMPOSITE PRICE FOR NO. 1
HEAVY MELTING STEEL
SCRAP IN 1991, WITH ANNUAL AVERAGES
FOR 1990 AND 1991

(Per long ton)

Month	Chicago	Philadelphia	Pittsburgh	Composite price
January	\$104.76	\$105.00	\$105.36	\$105.04
February	100.74	104.00	102.34	102.36
March	98.00	98.86	99.50	98.79
April	97.80	96.18	99.36	97.78
May	93.18	95.00	96.16	94.78
June	87.50	87.90	91.50	88.97
July	87.74	82.19	91.64	87.19
August	94.14	82.00	94.50	90.21
September	98.50	82.00	94.50	91.67
October	97.50	81.87	92.28	90.55
November	91.97	79.00	87.50	86.16
December	90.50	79.00	87.50	85.67
Annual average:				
1991	95.19	89.42	95.18	93.26
1990	108.62	106.21	106.61	107.15

Source: American Metal Market.

TABLE 17
U.S. EXPORTS¹ OF IRON AND STEEL SCRAP, BY COUNTRY²

(Thousand metric tons and thousand U.S. dollars)

Country	1987		1988		1989		1990		1991	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Canada	300	30,516	570	62,367	937	106,296	939	109,220	806	98,636
China	226	23,423	28	5,010	44	11,129	65	11,372	37	9,930
Italy	159	15,675	81	12,926	147	27,446	170	26,297	44	8,224
Japan	894	123,051	589	148,362	434	139,245	481	119,866	340	92,386
Korea, Republic of	2,386	213,550	2,139	271,155	2,710	404,815	2,931	409,677	2,784	381,691
Mexico	454	48,278	831	101,785	521	63,585	568	72,186	516	56,868
Spain	378	42,503	367	108,067	597	119,784	236	35,685	118	18,640
Taiwan	386	46,629	607	89,021	369	64,386	481	71,761	800	100,990
Turkey	2,045	195,971	1,801	230,853	2,926	393,503	2,748	335,781	1,776	196,626
Venezuela	136	10,273	234	26,109	74	8,166	45	5,243	6	1,108
Other	2,038	217,149	1,916	296,298	2,391	410,288	2,917	438,130	2,118	267,746
Total ³	9,405	967,018	9,161	1,351,955	11,149	1,748,643	11,580	1,635,218	9,345	1,232,845

¹Excludes used rails for rerolling and other uses and ships, boats, and other vessels for scrapping.

²U.S. exports were shipped to 57 countries in 1991 compared with 60 in 1990.

³Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 18
U.S. EXPORTS AND IMPORTS FOR CONSUMPTION OF IRON AND STEEL SCRAP, BY CLASS

(Thousand metric tons and thousand U.S. dollars)

Class	1987		1988		1989		1990		1991	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Export:										
No. 1 heavy melting scrap	2,219	200,980	2,177	255,370	2,530	308,485	2,479	297,504	2,263	243,849
No. 2 heavy melting scrap	525	45,994	627	68,102	953	109,101	804	91,587	766	79,869
No. 1 bundles	151	14,890	67	8,852	93	12,990	157	19,596	85	8,609
No. 2 bundles	332	23,623	337	31,567	419	41,505	340	32,489	401	34,717
Stainless steel scrap	156	94,025	220	239,807	265	320,683	233	212,368	232	196,380
Shredded steel scrap	3,006	298,259	2,640	343,188	3,496	486,999	3,674	482,465	2,161	247,519
Borings, shovels, turnings	479	28,835	467	36,230	674	55,765	247	20,442	173	13,191
Other steel scrap ¹	1,844	195,197	1,852	277,281	1,609	276,420	2,428	322,550	1,670	224,031
Iron scrap	691	65,217	773	91,557	1,110	136,694	1,218	156,217	1,593	184,681
Total²	9,405	967,018	9,161	1,351,955	11,149	1,748,643	11,580	1,635,218	9,345	1,232,845
Ships, boats, and other vessels for scrapping	223	20,264	299	43,548	114	16,698	23	3,842	114	8,158
Used rails for rerolling and other uses ³	52	8,863	38	7,330	55	20,062	48	14,385	48	12,422
Total exports²	9,680	996,145	9,498	1,402,833	11,319	1,785,403	11,651	1,653,445	9,507	1,253,425
Imports for consumption:										
Iron and steel scrap	765	82,016	942	133,577	1,016	149,109	1,309	171,510	1,073	142,552
Used rails for rerolling and other uses ³	—	—	—	—	89	14,844	154	25,148	93	16,173
Total imports²	765	82,016	942	133,577	1,105	163,953	1,464	196,658	1,166	158,725

¹Includes tinsplate and terneplate.

²Data may not add to totals shown because of independent rounding.

³Totals in 1990 and 1991 contain mixed (used plus new) rails. For 1990, exports contained 5,979 metric tons valued at \$4,439,351; imports contained no mixed rails. For 1991, exports contained 6,828 metric tons valued at \$3,963,245; imports contained no mixed rails.

Source: Bureau of the Census.

TABLE 19
U.S. EXPORTS OF USED RAILS FOR REROLLING AND OTHER USES,¹ BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1987		1988		1989		1990		1991	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Canada	1	170	1	134	4	774	6	3,966	5	2,762
Korea, Republic of	(²)	8	—	—	—	—	(²)	49	—	—
Mexico	41	7,346	36	6,794	48	14,569	35	8,810	41	8,599
Turkey	9	1,111	—	—	—	—	(²)	6	—	—
Other	1	228	1	401	4	4,719	6	1,553	2	1,061
Total ³	52	8,863	38	7,330	55	20,062	48	14,385	48	12,422

¹Exports in 1990 and 1991 contained mixed (used plus new) rails. For 1990, exports contained 5,979 metric tons valued at \$4,439,151. For 1991, exports contained 6,828 metric tons valued at \$3,963,245.

²Less than 1/2 unit.

³Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 20
U.S. IMPORTS FOR CONSUMPTION OF IRON AND STEEL SCRAP,¹ BY COUNTRY

Country	1989		1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Austria	16	\$27	—	—	—	—
Canada	862,790	121,454	1,083,779	\$134,150	892,941	\$104,016
France	26,769	207	118	258	15	86
Germany, Federal Republic of	3,399	1,215	931	791	2,229	2,609
Japan	59,687	5,885	67,113	7,170	52,417	6,331
Mexico	51,585	13,217	63,605	18,732	64,476	18,552
Netherlands	3,241	1,512	812	97	—	—
Sweden	82	211	8,828	43	—	—
U.S.S.R.	—	—	262	2,741	295	412
United Kingdom	324	905	28,350	1,347	9,400	950
Other	7,718	4,477	55,669	6,181	51,593	9,596
Total ²	1,015,612	149,109	1,309,466	171,510	1,073,366	142,552

¹Includes timplat and terneplate, excludes used rails for rerolling and other uses, and ships, boats, and other vessels for scrapping.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 21
U.S. IMPORTS FOR CONSUMPTION OF IRON AND STEEL SCRAP,¹ BY CLASS

Class	1989		1990		1991	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value
No. 1 heavy melting scrap	36,352	\$4,090,945	51,200	\$5,411,578	52,573	\$5,248,608
No. 2 heavy melting scrap	10,540	1,162,945	10,651	1,093,062	9,402	898,752
No. 1 bundles	64,567	8,130,056	140,584	16,207,757	94,238	10,463,921
No. 2 bundles	5,544	725,792	12,923	1,450,614	4,938	530,448
Stainless steel scrap	53,290	29,826,184	102,144	31,284,356	33,046	23,138,547
Shredded steel scrap	56,069	12,361,167	46,125	6,296,095	30,992	3,301,902
Borings, shovelings, turnings	15,214	1,388,505	28,794	2,959,970	31,218	2,888,257
Other iron and steel scrap	677,398	77,711,456	762,191	87,700,496	718,617	83,580,530
Cast iron scrap	96,639	13,711,619	154,854	19,106,205	98,342	12,500,758
Total	² 1,015,612	149,108,669	11,309,466	171,510,133	11,073,366	142,551,723

¹Excludes used rails for rerolling and other uses and ships, boats, and other vessels for scrapping.

²Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 22
U.S. IMPORTS FOR CONSUMPTION OF USED RAILS FOR REROLLING AND OTHER USES,¹ BY COUNTRY

Country	1989		1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	—	—	6	\$7,234	—	—
Canada	80,121	\$13,521,929	151,879	23,421,711	93,011	\$16,152,456
France	—	1,599	—	—	(²)	2,460
Germany, Federal Republic of	5	4,881	2,439	1,641,592	—	—
Israel	—	—	—	—	2	5,650
Japan	25	15,202	158	77,265	—	—
Mexico	—	—	—	—	20	12,000
U.S.S.R.	8,958	1,290,199	—	—	—	—
United Kingdom	5	10,674	—	—	—	—
Total³	89,115	14,844,484	154,483	25,147,802	93,033	16,172,566

¹Imports contained no mixed (used plus new) rails for 1990 and 1991.

²Less than 1/2 unit.

³Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 23
U.S. EXPORTS OF DIRECT-REDUCED IRON (DRI), BY COUNTRY¹

Country	1989			1990			1991					
	Metallic iron content of DRI product, weight percent			Metallic iron content of DRI product, weight percent			Metallic iron content of DRI product, weight percent					
	More than 80%	Minimum of 99.94%	Minimum of 99.94%	More than 80%	Minimum of 99.94%	Minimum of 99.94%	More than 80%	Minimum of 99.94%	Minimum of 99.94%			
Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value			
Argentina	292	\$218,294	2	\$4,915	360	\$264,877	40	\$23,200	333	\$239,803	214	\$136,820
Brazil	1,834	1,244,442	(²)	2,980	1,191	796,936	—	—	660	459,347	62	38,475
Canada	477	654,456	242	231,394	747	510,523	21	13,883	394	273,549	25	10,550
Colombia	83	48,298	11	18,820	10	4,250	—	—	6	4,791	4	17,408
Germany, Federal Republic of	27	76,888	32	27,028	223	469,872	28	34,944	184	156,900	85	200,990
Hong Kong	10	9,269	4	3,160	262	223,012	—	—	260	140,997	—	—
Japan	2,336	1,076,558	985	1,246,429	253	119,855	500	1,015,653	31	89,793	731	1,338,187
Korea, Republic of	70	22,743	118	516,285	4	9,532	(²)	3,200	38	35,132	4	36,269
Mexico	231	316,535	346	322,725	513	413,586	341	356,180	534	476,416	267	260,939
Netherlands	—	—	321	278,022	—	—	347	451,226	10	9,043	182	233,354
Peru	—	—	3	9,684	—	—	1	3,725	177	116,878	1	3,045
Saudi Arabia	—	—	36	37,201	111	52,539	—	—	145	170,577	19	35,475
Singapore	7	55,370	2	4,704	—	—	12	14,314	232	119,879	8	11,580
Taiwan	464	247,461	41	27,394	73	47,440	396	207,383	—	—	29	27,598
United Kingdom	3	40,262	24	41,537	—	—	42	74,759	5	24,603	223	138,424
Venezuela	14	12,591	47	98,532	74	51,521	73	44,548	168	104,481	356	208,035
Other Countries	86	283,531	146	231,162	126	343,424	220	343,586	340	444,572	204	201,752
Total	5,934	4,306,698	2,360	3,101,972	3,947	3,307,367	2,021	2,586,601	3,517	2,866,761	2,414	2,898,901

¹Data are currently being reviewed by Bureau of the Census.

²Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 24
U.S. IMPORTS FOR CONSUMPTION OF DIRECT-REDUCED IRON (DRI), BY COUNTRY

Country	1989			1990			1991			
	Metallic iron content of DRI product, weight percent			Metallic iron content of DRI product, weight percent			Metallic iron content of DRI product, weight percent			
	More than 80%	Minimum of 99.94%	Quantity (metric tons)	More than 80%	Minimum of 99.94%	Quantity (metric tons)	More than 80%	Minimum of 99.94%	Quantity (metric tons)	
Australia	907	\$562,000	—	—	—	—	—	—	1	\$1,678
Belgium	17	88,695	3	\$6,627	—	—	100	\$11,940	38	48,478
Brazil	—	—	—	—	—	—	—	—	4,301	5,550,936
Canada	1,036	708,796	212	130,393	458	360,927	—	—	207	101,963
China	—	—	—	—	—	—	—	—	9	11,400
Germany, Federal Republic of	—	—	7	21,317	17,183	1,666,770	1	\$1,295	7	8,622
Hong Kong	—	—	1	1,715	(¹)	1,800	—	—	—	—
Italy	41	50,238	—	—	20	20,860	—	—	7	2,155
Jamaica	—	—	—	—	820	278,749	—	—	—	—
Japan	1,207	277,075	483	1,148,888	—	—	516	596,015	40	4,270
Korea, Republic of	—	—	—	—	—	—	—	—	—	—
Mexico	—	—	2	1,166	—	—	5	5,359	20	1,986
Netherlands	—	—	20	94,140	—	—	—	—	—	—
Norway	88	17,706	—	—	—	—	—	—	—	—
Peru	—	—	—	—	—	—	—	—	7	19,203
Singapore	—	—	29	10,98	—	—	—	—	—	—
Spain	—	—	—	—	—	—	—	—	—	—
Sweden	38	46,269	1	4,347	—	—	—	—	21	24,360
Taiwan	—	—	1	9,240	—	—	—	—	—	—
U.S.S.R.	—	—	—	—	38,406	6,548,901	24,219	2,536,940	19,345	2,050,634
United Kingdom	4	2,520	87	312,999	—	—	9	45,476	—	—
Venezuela	148,547	17,035,945	17,855	2,090,281	212,353	23,730,826	39,303	4,451,445	345,148	38,507,445
Grand total	151,885	18,789,244	18,701	3,832,102	269,594	33,337,602	64,053	7,636,530	364,674	40,600,635
									15,245	13,023,444

¹Data currently being reviewed by Bureau of the Census.

²Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 25
IRON AND STEEL SCRAP CONSUMPTION IN SELECTED COUNTRIES¹

(Thousand metric tons)

Continent, country group, and country	1986	1987	1988	1989	1990
North America:					
Canada ²	7,826	8,200	*8,500	*8,900	*8,500
United States ^{3 4}	59,744	61,963	69,692	65,507	70,451
Latin America:⁵					
Argentina	1,137	1,310	1,326	*1,254	1,221
Brazil	7,198	7,319	7,676	*8,032	6,500
Chile	138	219	290	*279	*270
Colombia	445	538	562	*571	*560
Ecuador	18	27	25	*27	*25
Mexico	2,951	2,580	3,422	*3,010	*3,350
Peru	265	311	276	*175	*130
Trinidad and Tobago	138	153	254	*107	*110
Uruguay	37	36	37	*46	*46
Venezuela	904	1,165	1,291	*1,417	*1,330
Central America, not further detailed	138	137	124	110	95
Europe:					
European Community:⁶					
Belgium	*2,677	*2,546	*3,157	*2,932	3,137
Denmark	704	*626	652	631	608
France	*6,588	6,711	6,844	*6,920	7,396
Germany, Federal Republic of	*12,952	*12,238	*13,296	*12,917	12,535
Greece	1,107	1,012	1,077	1,071	1,095
Ireland	232	246	*303	*362	364
Italy	*14,756	14,884	15,552	16,839	16,436
Luxembourg	*1,468	1,309	1,474	1,415	1,373
Netherlands	*1,306	*1,159	1,197	*1,111	1,009
Portugal	382	393	468	*492	531
Spain	*8,916	*8,588	8,985	9,196	8,720
United Kingdom	6,661	7,061	*7,759	*7,880	7,011
European Free Trade Association:					
Austria ⁷	1,465	1,473	1,466	1,506	*1,375
Finland ⁷	759	1,457	1,301	1,361	*1,330
Norway ^{7 8}	544	632	691	481	*275
Sweden ^{3 7 8}	2,939	2,953	2,991	*2,900	*2,750
Switzerland ⁹	1,000	1,000	1,100	*900	900
Council for Mutual Economic Assistance:					
Bulgaria	771	862	907	*1,900	*1,450
Czechoslovakia ^{3 8 9}	7,640	8,214	8,127	7,683	6,847
German Democratic Republic ^{3 7 8 9}	5,004	5,118	5,069	5,101	*3,600
Hungary	2,642	2,470	2,236	2,018	1,653
Poland ⁷	9,135	9,266	*9,128	*7,900	*7,100
Romania ⁹	3,900	4,100	4,300	3,600	1,500
U.S.S.R.	70,035	70,942	72,030	*63,500	*61,500
Other: Yugoslavia ¹⁰	2,289	*2,488	*2,736	*3,004	2,466
Africa: South Africa, Republic of³	3,175	3,175	3,400	3,600	3,350

See footnotes at end of table.

TABLE 25—Continued
IRON AND STEEL SCRAP CONSUMPTION IN SELECTED COUNTRIES¹

(Thousand metric tons)

Continent, country group, and country	1986	1987	1988	1989	1990
Asia:					
China ^a	11,340	12,250	12,700	13,200	14,200
India ^a	4,000	4,000	4,100	4,500	4,600
Japan ^a	40,259	40,621	42,976	45,836	46,900
Korea, Republic of ^a	3,450	3,650	4,100	4,600	4,860
Taiwan ^a ¹¹	1,600	1,800	2,000	2,100	2,300
Turkey ¹²	1,996	2,268	2,495	2,450	2,900
Oceania:					
Australia	1,814	1,558	1,365	1,442	1,506
New Zealand ^a	135	135	145	180	200
Total	314,580	321,164	339,603	330,964	326,365

^aEstimated. ^bRevised.

¹Unless otherwise noted, figures represent reported consumption of iron and steel scrap utilized in the production of pig iron, ferroalloys, crude steel, foundry products, and rerolled steel, as well as other unspecified uses in the steel industry and by other unspecified industries as reported by the United Nations Economic Commission for Europe in its Annual Bulletin of Steel Statistics for Europe, 1989, v. 17, New York, 1990, 28 pp., which is the source of all reported data unless otherwise noted. All estimates are by the U.S. Bureau of Mines.

²Source: Canadian Foundry Association as reported by Energy, Mines, and Resources Canada.

³Excludes used rails for rerolling and other uses and ships, boats, and other vessels for scrapping.

⁴Source: U.S. Bureau of Mines.

⁵Reported data are from Instituto Latino Americano del Fierro y el Acero. Statistical Yearbook of Steel Making and Iron Ore Mining in Latin America, 1989, Santiago, 1990, 231 pp. Source does not provide details on what is included; presumably figures include total steel industry ferrous scrap consumption but exclude scrap used outside the steel industry.

⁶Source: Eurostat. Iron and Steel, Luxembourg, monthly and annual issues. Data include consumption in blast furnaces, melting shops, rolling mills, and independent steel foundries.

⁷Excludes scrap consumed in iron foundries.

⁸Excludes scrap consumed within the steel industry for purposes other than the manufacture of pig iron, ferroalloys, crude steel, foundry products, and rerolled steel (details on use not available).

⁹Excludes scrap consumed outside the steel industry.

¹⁰Source: Industrija. Belgrade, 1986-90 editions.

¹¹Source: Organization for Economic Cooperation and Development. The Iron and Steel Industry in 1985, Paris, 1987, 52 pp.; The Iron and Steel Industry in 1986, Paris, 1988, 52 pp.; The Iron and Steel Industry in 1987, Paris, 1988, 52 pp.; and The Iron and Steel Industry in 1988, Paris, 1989, 52 pp.

¹²Excludes a substantial tonnage derived from shipbreaking, possibly in the order of several million tons annually, for electric-furnace-equipped steel mills.

TABLE 26
IRON AND STEEL SCRAP EXPORTS, BY SELECTED COUNTRIES¹

(Thousand metric tons)

Continent, country group, and country	1986	1987	1988	1989	1990
North America:					
Canada ²	922	1,087	1,682	900	1,372
United States ^{2 3}	10,688	⁹ 9,457	9,199	¹¹ 11,204	11,628
Latin America:					
Cuba ⁴	111	150	61	⁹⁰	⁹⁰
Mexico ²	22	23	47	³⁰	⁵⁰
Europe:					
European Community:					
Belgium-Luxembourg	658	752	914	¹ 1,050	⁸ 869
Denmark	183	223	298	279	³ 310
France	3,161	3,228	3,692	4,260	³ 3,676
Germany, Federal Republic of	3,418	4,218	4,597	4,847	²⁵ 5,043
Greece	1	2	3	3	²
Ireland	41	26	32	34	²⁶
Italy	7	16	28	30	¹⁹
Netherlands	1,989	2,244	2,650	2,773	²² 2,594
Portugal	11	7	13	²¹	¹⁵
Spain	1	16	60	29	²³
United Kingdom	3,837	3,583	3,624	3,265	³ 3,198
European Free Trade Association:					
Austria	22	92	47	96	³ 342
Finland	—	—	—	1	²
Iceland	3	10	5	4	⁴
Norway	8	12	21	20	¹²
Sweden	29	44	96	¹⁴²	¹²²
Switzerland ²	61	87	78	67	66
Council for Mutual Economic Assistance:					
Bulgaria	4	35	36	32	³⁵
Czechoslovakia ⁴	102	100	163	167	¹⁷⁵
German Democratic Republic ⁴	7	11	15	¹⁸	²⁰
Hungary	6	107	151	⁹¹	¹²⁵
Poland ²	73	97	347	440	425
U.S.S.R.	⁴ 4,088	³ 3,900	3,231	2,732	² 2,500
Other: Yugoslavia	158	367	362	228	² 218
Africa:					
Algeria ²	149	151	142	¹⁶⁰	¹⁷⁵
Morocco ²	52	63	92	96	84
South Africa, Republic of ²	146	71	54	68	⁷⁵
Asia:					
Bahrain ⁶	10	10	10	10	10
Brunei ⁶	10	10	10	10	10
China ²	³	100	686	¹⁸⁵	112
Cyprus	14	5	16	34	²
Hong Kong ²	276	320	371	⁴⁷⁴	480
India ⁶	20	20	25	30	35
Indonesia ²	6	3	5	1	1

See footnotes at end of table.

TABLE 26—Continued
IRON AND STEEL SCRAP EXPORTS, BY SELECTED COUNTRIES¹

(Thousand metric tons)

Continent, country group, and country	1986	1987	1988	1989	1990
Asia—Continued:					
Japan	461	377	416	587	² 396
North Korea ⁴	25	21	24	² 21	² 30
Korea, Republic of ²	72	42	41	19	40
Kuwait ⁴	91	91	91	² 160	100
Malaysia ²	46	44	81	² 75	² 75
Philippines ²	1	1	2	2	2
Saudi Arabia ⁴	32	45	² 124	² 140	² —
Singapore ²	91	156	266	239	300
Taiwan ²	281	98	75	52	69
Thailand ²	5	5	5	² 7	10
Turkey	5	5	7	² 4	² 7
United Arab Emirates ⁴	10	10	10	10	10
Vietnam ⁴	92	84	131	² 370	² 350
Oceania:					
Australia ²	565	875	11	55	220
New Zealand ²	4	3	2	² 34	61
Total	²32,075	²32,505	²34,149	²35,696	35,615

¹Estimated. ²Revised.

¹Unless otherwise noted, source is United Nations Economic Commission for Europe. Annual Bulletin of Steel Statistics for Europe, 1989, v. 17, New York, 1990, 38 pp.

²Source: Official trade returns of subject country.

³Includes used rails for rerolling and other uses; excludes ships, boats, and other vessels for scrapping.

⁴Partial figure; compiled from import statistics of trading partner country.

TABLE 27
IRON AND STEEL SCRAP IMPORTS, BY SELECTED COUNTRIES¹

(Thousand metric tons)

Continent, country group, and country	1986	1987	1988	1989	1990
North America:					
Canada ²	751	779	1,152	1,462	1,003
United States ^{2 3}	657	765	942	1,016	1,309
Latin America:					
Argentina ²	1	1	1	¹ 11	19
Brazil ²	491	146	⁸ 7	² 64	² 50
Chile	² 17	² 3	¹ 8	¹ 8	(²)
Colombia ²	⁴ 5	⁴ 5	157	² 05	² 00
Cuba ⁴	89	⁹ 0	⁹ 0	⁹ 0	⁷ 5
Mexico ²	431	465	835	⁶ 56	⁷ 00
Peru ⁴	20	20	20	20	20
Venezuela ⁴	500	500	635	635	600
Europe:					
European Community:					
Belgium-Luxembourg	1,223	1,585	1,904	² 1,976	² 1,885
Denmark	121	89	117	105	² 74
France	353	519	802	871	² 997
Germany, Federal Republic of	1,377	1,190	1,408	1,234	² 1,041
Greece	456	654	³ 427	³ 429	² 526
Ireland	122	149	180	221	² 217
Italy	4,750	4,914	5,064	5,749	² 5,808
Netherlands	850	1,042	770	1,109	² 1,160
Portugal	103	92	180	² 149	² 82
Spain	4,343	4,269	4,509	4,496	² 4,291
United Kingdom	47	73	103	111	² 60
European Free Trade Association:					
Austria	115	69	102	88	² 55
Finland	64	54	16	² 34	² 46
Norway	6	32	164	61	² 23
Sweden	698	790	795	² 626	² 247
Switzerland ²	324	136	85	153	² 136
Council for Mutual Economic Assistance:					
Czechoslovakia ⁴	⁴ 3	2	2	2	2
German Democratic Republic	⁴ 987	⁴ 903	⁴ 910	⁴ 770	⁴ 500
Hungary	8	14	5	⁵ 5	⁵ 5
Poland ²	5	6	3	⁵ 5	6
U.S.S.R. ⁴	⁶ 44	45	45	45	40
Other: Yugoslavia	652	689	746	646	² 413
Africa:					
Egypt ²	2	2	12	³ 34	³ 35
Morocco ²	4	2	2	(¹)	2
South Africa, Republic of	45	23	27	18	² 0
Asia:					
Bahrain ⁴	3	3	3	3	3
China ²	⁴ 650	498	154	¹ 20	183
Hong Kong ²	34	44	86	76	82
India ⁴	1,590	1,815	2,020	1,690	2,245
Indonesia ²	476	461	586	719	1,178

See footnotes at end of table.

TABLE 27—Continued
IRON AND STEEL SCRAP IMPORTS, BY SELECTED COUNTRIES¹

(Thousand metric tons)

Continent, country group, and country	1986	1987	1988	1989	1990
Asia—Continued:					
Japan	3,227	2,360	1,792	1,158	1,048
Korea, Republic of ²	3,118	3,522	3,895	4,066	3,876
Malaysia ²	5	222	⁴ 489	⁷ 18	⁷ 25
Pakistan ²	147	587	⁴ 701	³ 75	⁴ 00
Philippines ²	85	109	94	⁹ 4	⁹ 0
Saudi Arabia ²	1	182	541	192	² 00
Singapore ²	209	127	182	197	221
Syria ³	15	15	15	15	15
Taiwan ²	1,227	944	1,257	¹ 553	1,287
Thailand ²	556	904	1,159	¹ 081	1,101
Turkey	² 1,800	2,834	3,040	² 4,422	³ 650
Oceania:					
Australia ³	1	1	1	5	5
New Zealand ²	5	5	(⁵)	(⁵)	(⁵)
Total	³2,894	³4,808	⁴2,330	³9,793	38,154

¹Estimated. ²Revised.

¹Unless otherwise noted, source is United Nations Economic Commission for Europe. Annual Bulletin of Steel Statistics for Europe, 1989, v. 17, New York, 1990, 38 pp.

²Source: Official trade returns of subject country.

³Excludes used rails for re-rolling and other uses and ships, boats, and other vessels for scrapping.

⁴Partial figure; compiled from export statistics of trading partner countries.

⁵Less than 1/2 unit.

⁶Partial figure; compiled from incomplete returns of subject country and export statistics of trading partner countries.

TABLE 28
SHREDDER PROCESSING CAPACITY¹ IN SELECTED COUNTRIES IN 1990

Country	Total number of shredders in operation, including mills	Total power requirements (horsepower)	Total annual capacity and/or output ² (thousand metric tons)	Number of new plants under construction	Average power requirements per shredder (horsepower)	Average annual capacity and/or output per shredder (thousand metric tons)	Average power requirements of annual capacity and/or output (horsepower per metric ton)
North America:							
Canada	22	60,000	1,500	—	2,700	68	0.040
Mexico	4	6,600	*145	—	1,700	*36	*.046
United States	*210	*560,000	*15,000	4	*2,700	*71	*.037
Geographic area	*236	*626,600	*16,645	4	*2,700	*71	*.038
South America:							
Argentina	1	2,000	*43	—	2,000	*43	*.047
Brazil	3	5,000	*126	—	1,700	*42	*.040
Colombia	3	5,000	*109	—	1,700	*36	*.046
Venezuela	1	4,000	*86	—	4,000	*86	*.047
Geographic area	8	16,000	*364	—	2,000	*45	*.044
Western Europe:							
Austria	6	*7,500	120	—	*1,250	20	*.063
Belgium-Luxembourg	10	13,750	375	—	1,370	37	.037
Denmark	5	6,400	100	—	1,300	20	.064
Finland	3	*5,750	*90	1	*1,900	*30	*.064
France	34	45,790	1,400	9	1,350	41	.033
Germany, Federal Republic of	44	56,760	1,570	—	1,290	36	.036
Ireland	1	1,250	30	—	1,250	30	.042
Italy	*15	*21,400	*750	*1	*1,430	*50	*.029
Netherlands	10	11,300	450	—	1,130	45	.025
Norway	3	2,900	112	—	970	37	.026
Portugal	2	*2,250	*47	—	*1,100	*24	*.048
Spain	12	14,500	*310	1	1,200	*26	*.047
Sweden	4	*9,750	*210	1	*2,400	*53	*.046
Switzerland	4	*5,000	*110	—	*1,250	*27	*.045
Turkey	1	2,000	*43	—	2,000	*43	*.047
United Kingdom	55	110,000	*2,100	1	2,000	*38	*.052
Geographic area	209	*316,300	*7,817	14	*1,500	*37	*.040
Eastern Europe:							
Czechoslovakia	2	5,000	*100	—	2,500	*50	*.050
German Democratic Republic	2	*3,750	*81	—	*1,900	*41	*.046
U.S.S.R.	6	*11,300	*240	—	*1,900	*41	*.047
Yugoslavia	1	1,250	*27	—	1,250	*27	*.046
Geographic area	11	*21,300	*448	—	*1,900	*41	*.048
Africa:							
South Africa, Republic of	5	*9,250	*277	1	*1,850	*55	*.033
Geographic area	5	*9,250	*277	1	*1,850	*55	*.033
Far East:							
Japan	145	*121,100	*3,633	10	*840	*25	*.033
Singapore	1	1,400	*42	—	1,400	*42	*.033
Taiwan	1	1,230	*37	—	1,230	*37	*.033
Geographic area	147	*123,730	*3,712	10	*840	*25	*.033
Middle East:							
Abu Dhabi	1	*1,250	*27	—	*1,250	*27	*.046
Iraq	1	*1,250	*27	—	*1,250	*27	*.046

See footnotes at end of table.

TABLE 28—Continued
SHREDDER PROCESSING CAPACITY¹ IN SELECTED COUNTRIES IN 1990

Country	Total number of shredders in operation, including mills	Total power requirements (horsepower)	Total annual capacity and/or output ² (thousand metric tons)	Number of new plants under construction	Average power requirements per shredder (horsepower)	Average annual capacity and/or output per shredder (thousand metric tons)	Average power requirements of annual capacity and/or output (horsepower per metric ton)
Middle East—Continued:							
Kuwait	1	*2,000	*43	1	*2,000	*43	*.047
Libya	1	*1,250	*27	—	*1,250	*27	*.046
Qatar	1	*1,500	*32	—	*1,500	*32	*.047
Saudi Arabia	2	*4,500	*98	—	*2,300	*49	*.046
Geographic area	7	*11,750	*254	1	*1,700	*36	*.046
Oceania:							
Australia	9	*20,700	*440	—	*2,300	*49	*.047
New Zealand	1	*2,000	*43	—	*2,000	*43	*.047
Geographic area	10	*22,700	*483	—	*2,300	*48	*.047
World total	*633	*1,147,630	*30,000	30	*1,810	*47	*.038

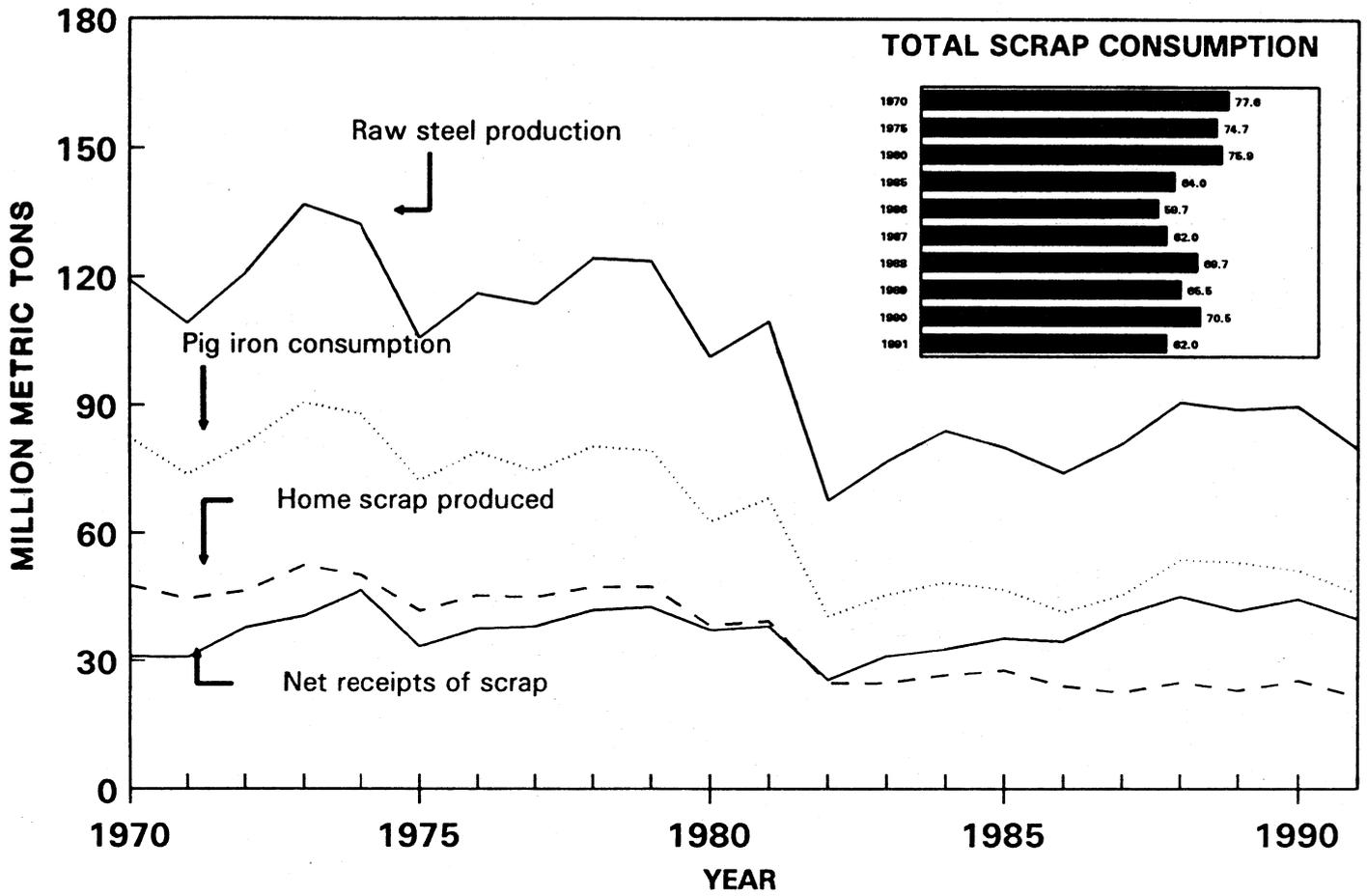
*Estimated.

¹Unless otherwise specified, source for figures developed by the U.S. Bureau of Mines is from the Institute of Scrap Recycling Industries, Inc., the Bureau International de la Recuperation (BIR), manufacturers of shredders, or shredder operators.

²Assumed shredders were operated 8 hours per day, 5 days per week, 11 months per year (to allow for downtime, holidays, and planned maintenance), at 70% capacity.

FIGURE 1

RAW STEEL PRODUCTION (AISI), FOR ALL TYPES OF MFR'S COMBINED: TOTAL IRON AND STEEL SCRAP CONSUMPTION, PIG IRON CONSUMPTION, HOME SCRAP PRODUCTION, AND NET SCRAP RECEIPTS



KYANITE AND RELATED MATERIALS

By Michael J. Potter

Mr. Potter, a physical scientist, has been the commodity specialist for kyanite since 1975. Domestic survey data were prepared by Joe Daniels, statistical assistant; and the international data table was prepared by Virginia Woodson, international data coordinator.

Kyanite, andalusite, and sillimanite are anhydrous aluminum silicate minerals of the same composition represented by the chemical formula $\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$. Related materials include synthetic mullite, dumortierite, and topaz, also classified as aluminum silicates, although the last two additionally contain substantial proportions of boron and fluorine, respectively. The largest end use of kyanite group minerals and mullite is in the manufacture of high-alumina, high-performance refractories, including brick and shapes and monolithic refractory applications such as for high-temperature mortars or cements, ramming mixes, and castable refractories.

U.S. production of kyanite was estimated to have decreased slightly compared with that of 1990 because of a generally sluggish economy and reduced activity in the iron and steel industry. Domestic synthetic mullite output decreased compared with that of the previous year. Imports of andalusite in 1991 were approximately 5,100 metric tons compared with 17,700 metric tons in 1990.

DOMESTIC DATA COVERAGE

There are two known domestic kyanite mine-and-mill operations, but data are not known and would not be publishable because of company proprietary data. Of the three known synthetic mullite producers, all responded to the voluntary domestic survey. However, data cannot be published because of possible revealing of company proprietary data.

BACKGROUND

Definitions, Grades, and Specifications

Kyanite, andalusite, and sillimanite are a closely related trio of aluminum silicate minerals, differing slightly in physical properties and crystallographic characteristics, but sharing the same chemical composition, which can be represented as $\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$. When heated, kyanite begins to break down to a noticeable extent at 1,315° C (andalusite at 1,382° C and sillimanite at 1,549° C) to form a mixture of mullite, $3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$, and vitreous silica, SiO_2 . The mullite so produced usually consists of an aggregation of interlocking, acicular crystals and remains dimensionally and chemically stable until the temperature is raised to at least 1,810° C. These properties enable mullite to serve as a component in refractory shapes and furnace linings for a wide range of industrial applications. Above 1,810° C, mullite dissociates slowly with little change in volume into corundum (Al_2O_3) and silica, which recombine to form mullite at a lower temperature.

Topaz, $\text{Al}_2\text{SiO}_4(\text{F}, \text{OH})_2$, and dumortierite, $\text{Al}_7(\text{BO}_3)(\text{SiO}_4)_3\text{O}_3$, are also often classed as members of the kyanite group of minerals. Upon firing, topaz loses fluorine and dumortierite loses boron, yielding refractory residues consisting essentially of mullite. A number of other substances—fire clay, siliceous bauxite, and kaolin, for example—owe their ability to perform satisfactorily in some refractory applications to the fact that, when heated, at least part of the aluminum silicate they contain is converted to mullite.

There are three types of synthetic mullite. Low-temperature sintered synthetic mullite is made by sintering siliceous bauxite or mixtures of bauxite and kaolin above 1,549° C. High-temperature sintered synthetic mullite is prepared by sintering mixtures of alumina and kaolin, bauxite and kaolin, or alumina, kaolin, and kyanite above 1,749° C. Fused synthetic mullite is made by melting Bayer-process alumina and silica or bauxite and kaolin in an electric furnace at about 1,900° C.

All domestic kyanite ore is ground to permit separation and recovery by froth flotation of the mineral particles from accompanying gangue. The flotation concentrate product is graded for sale to consumers in five particle-size ratings: 35, 48, 100, 200, and 325 mesh. Kyanite concentrates may contain from 56% to 60% alumina, from 38% to 44% silica, and from 0.2% to 0.9% iron oxide. Lump kyanite from India, ranging in size from pea to boulders, was formerly imported into the United States. Indian reserves are limited, however, and material is no longer being exported.

Products for Trade and Industry

Kyanite and related materials are consumed in the manufacture of high-alumina or mullite-class refractories and in lesser quantities as ingredients in ceramic compositions. U.S. kyanite is marketed either in raw form or after heat treatment as mullite. In the 35- to 48-mesh range, kyanite is used in monolithic refractory applications such as high-temperature mortars or cements, ramming mixes, and castable refractories or with clays and other ingredients in refractory

compositions for making kiln furniture, insulating brick, firebrick, and a wide variety of other articles. More finely ground material, minus 200 mesh, is used in body mixes for sanitary porcelains, wall tile, investment-casting molds, and miscellaneous special purpose ceramics.

Data on the properties of finished refractory products are available from the producing firms. However, selection of the best refractory available for a specific application can sometimes be made only by testing under actual operating conditions. Load-bearing capacity, slag resistance, spalling characteristics, and other factors are often of prime importance.

Zircon sand containing some kyanite, sillimanite, and/or staurolite is used for foundry and refractory sand.

Technology

Both mines of the one U.S. kyanite producer are open pit, hard-rock quarrying operations. Blasted material is reduced to manageable size by drop-ball breaking and trucked to the processing plants where it is crushed to minus 1-inch size in jaw and cone crushers and then ground in rod mills to minus 35 mesh or finer. Two stages of flotation with alkaline-fatty acid or acid-petroleum sulfonate collectors produce an intermediate kyanite concentrate, which after being freed from iron by high-intensity magnetic treatment, becomes a salable product. Some kyanite is calcined at about 1,593° C and sold as mullite.

Byproducts and Coproducts

Quartzitic waste tailings from kyanite concentrators may be marketed locally as construction sand, but transportation costs limit the shipping radius of this byproduct.

Andalusite occurs in pyrophyllite ores that are mined by a company for ceramic and refractory purposes in North Carolina. A zircon-refractory heavy-mineral sand produced in Florida contains a small amount of aluminum silicates (kyanite, sillimanite, and staurolite) and is used for foundry and refractory sand.

Substitutes

Substitute and alternative materials for kyanite-group and mullite products in refractories include fire clay, calcined bauxite, and alumina. Other materials such as magnesite, chromite, silicon carbide, and zircon are interchangeable for specific end uses and conditions. Local availability of refractory raw materials is an important factor in choosing refractory products because transportation costs may prohibit use of alternative, technically superior materials.

ANNUAL REVIEW

Legislation

The allowable depletion rates for kyanite, established by the Tax Reform Act of 1969 and unchanged through 1991, were 22% for domestic production and 14% for foreign operations.

Production

Kyanite was produced at two open pit mines by Kyanite Mining Corp.: the Willis Mountain and East Ridge Mines in Buckingham County, VA. The company also operated beneficiation plants and calcining facilities for conversion of kyanite to mullite.

High-temperature sintered mullite was produced by C-E Minerals at Americus, GA, and North American Refractories Co. at Greenup, KY. (North American was previously known as Didier Taylor Refractories Corp. until mid-1991).¹ Electric-furnace-fused mullite was produced by Washington Mills Electro Minerals Corp. at Niagara Falls, NY.

Consumption and Uses

The U.S. Bureau of Mines does not collect data on end uses of kyanite and synthetic mullite. However, refractories for the iron and steel industries were probably the major end use of kyanite-mullite, consuming an estimated 55% of the quantity produced. Nonferrous metallurgical operations were believed to be the next largest use, estimated at 20%.

A third category, estimated at 15%, consisted of glassmaking furnaces, ceramic kilns, boilers, petroleum-processing equipment, etc. Nonrefractory uses were estimated to make up the remaining 10%.

In the iron and steel industries, mullite is important in critical areas of blast furnace stoves and stacks, reheat furnaces, steel degassing chambers and soaking pits, and many types of auxiliary pouring and handling equipment. In the nonferrous metal industry, an end-use example is in refractory linings of alumina reduction cells.

In glassmaking, fused mullite refractories can be used in the ports, which are at the side or end of a glass furnace. The port comes under attack from gases from the furnaces, as well as alkalis, lime, and silica particles carried through by the gases. Fuel oil ash and sulfur dioxide can also be carried through. The fused mullite is very slow wearing and able to withstand the high velocity and dust-laden gases.²

Uses for the andalusite-pyrophyllite products marketed by Piedmont Minerals, Hillsborough, NC, included soaking pit refractories in the form of plastics, gunning mixes, and castables; other uses were kiln car blocks, mortars, foundry washes, and other uses.³

Other miscellaneous uses include kiln furniture, blown aluminum silicate high-temperature insulation, brake linings, foundry mold facings, glass additions for alumina contents, ceramic tile, pyrometer tubes, high-tension insulators, spinnable mullite fibers, shell castings, ceramic honeycomb, mortars, grinding media, whitewares, extrusion dies, and welding rod coatings.

Prices

Prices at yearend 1991, in British pounds, from Industrial Minerals (London) were unchanged from those of the previous year. The apparent price decreases for 1991 in table 1 are the result of a stronger U.S. dollar against the British pound than that in 1990. (See table 1.)

Foreign Trade

Shipments of U.S. kyanite, mullite, and synthetic mullite were believed to have been made to foreign destinations, including Europe and Asia. Imports of andalusite, mostly from the Republic of South Africa, were approximately 5,100 metric tons with a customs value of \$933,000, according to the U.S. Department of Commerce. (See tables 2 and 3.)

World Review

Capacity.—Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

The data in table 3 are rated capacity for mines and refineries as of December 31, 1991. Some capacity data for Japan, the Republic of South Africa, and Sweden were obtained from literature sources. For other countries, recent peak production or estimated production was considered to be equal to rated capacity.

Australia.—Ramsgate Resources Ltd. was conducting exploration and development work on an andalusite deposit in the mining center of Spargoville, west of Kambalda in Western Australia's Eastern Goldfield. The property was reported to contain several occurrences of outcropping andalusite-bearing chlorite-biotite schist. Analyses of a small number of samples of the Spargoville andalusite indicated a high-quality material.⁴

Bolivia.—Andalusite-bearing deposits were identified in the northern part of the Cordillera Real (Andes Mountains) in Larecaja Province, La Paz. Andalusite

content was estimated to be 10%, outcropping in a continuous belt 12 kilometers long and at least 400 meters wide. Andalusite was also found in the fluvial sand deposits of the Mapiri region, associated with rutile, tourmaline, and zircon.⁵

China.—Andalusite occurs in the Provinces of Henan and Liaoning. Outside testwork indicated material with 55% to 60% Al₂O₃ and 1% to 2% Fe₂O₃, which is higher than the 1.0% maximum iron content of andalusite shipped from the Republic of South Africa. There were preliminary indications that the iron in some Chinese andalusite may be locked up within the large andalusite crystals. This situation could make it difficult to obtain an acceptable material by beneficiation.⁶ (See tables 4 and 5.)

Current Research

A magnetic separator recently developed by International Process Systems, Inc., of Golden, CO, was said to have solved the problem of limited operating life of the very thin belts used in rare-earth magnetic roll separators. The new separator was developed for dry applications, with five basic magnetic strength levels being offered. Possible applications were said to include coarse particles (greater than 2 millimeters) such as kyanite-group minerals and other ores and materials.⁷

OUTLOOK

The sluggish economy and reduced activity in the iron and steel industry were believed to be contributing factors affecting kyanite-mullite demand in 1991. New technology, such as continuous casting, has reduced demand for refractories in, for example, soaking pits. However, kyanite-mullite demand in the near future should remain stable because of continued improvement in product quality, handling, transportation, shipping, etc. Also, new uses and applications are being found.⁸

¹Glass Industry. Supplier News. V. 72, No. 7, June 1991, p. 35.

²Harries-Rees, K. Refractories in the Glass Industry. Ind. Miner. (London), No. 287, Aug. 1991, p. 39.

³Stowers, R. Andalusite, Am. Ceram. Soc. Bull., v. 70, No. 5, p. 851.

⁴Industrial Minerals (London). World of Minerals. No. 283, Apr. 1991, p. 9.

⁵Arduz, M., E. Arteaga, and G. Cancelliere. Industrial Minerals in Bolivia. Ind. Miner. (London), No. 285, June 1991, p. 81.

⁶McCracken, W. H., and W. G. Holroyd. Chinese Refractory Raw Materials in the 1990's. Ind. Miner. (London), No. 280, Jan. 1991, p. 32.

⁷Mining Journal (London). Technology Today. V. 316, No. 8105, Jan. 18, 1991, p. 44.

⁸Kay, C. Kyanite. Am. Ceram. Soc. Bull., v. 70, No. 5, May 1991, p. 870.

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Bennett, P. J., and J. E. Castle. Kyanite and Related Minerals. Ch. in Industrial Minerals and Rocks. American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, 5th ed., 1983, pp. 799-807.

Dickson, T. Sillimanite Minerals. Metals & Minerals Annual Review—1991, June 1991, pp. 104-105.

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TABLE 1
PRICE OF KYANITE AND RELATED MATERIALS

(Dollars per metric ton)

	1990	1991
Andalusite, Transvaal, 57% Al ₂ O ₃ , bulk, c.i.f. main European port	171-190	157-175
Andalusite, Transvaal, 60% Al ₂ O ₃ , c.i.f. main European port	247	227
Sillimanite, South African, 70% Al ₂ O ₃ , bags, c.i.f. main European port	361	332
U.S. kyanite, 59% to 62% Al ₂ O ₃ , 35-325 mesh, raw and/or calcined, 18-ton lots, c.i.f. main European port	171-295	157-271
U.S. kyanite, f.o.b. plant, carlots:		
Raw	70-137	70-137
Calcined	123-172	123-172

Source: Industrial Minerals (London). Dec. 1990, No. 279, p. 79, and Dec. 1991, No. 291, p. 63.

TABLE 2
U.S. IMPORT DUTIES

Tariff item	HTS No.	Most favored nation (MFN) Jan. 1, 1992	Non-MFN Jan. 1, 1992
Kyanite, sillimanite, andalusite, and dumortierite	2508.5	Free	Free.
Mullite	2508.6	4.9% ad valorem	30% ad valorem.

TABLE 3
**U.S. IMPORTS¹ FOR
CONSUMPTION OF ANDALUSITE**

Year	Quantity (metric tons)	Value ² (thousands)
1989	10,300	\$1,551
1990	17,700	2,942
1991	5,140	933

¹Data available beginning in 1989 under new Harmonized System. Most material is from the Republic of South Africa.

²Customs value.

Source: Bureau of the Census.

TABLE 4
WORLD KYANITE AND RELATED
MINERALS CAPACITY,
DECEMBER 31, 1991

(Thousand metric tons)

	Capacity
North America:	
United States:	
Kyanite	W
Synthetic mullite	W
Total	W
South America:	
Brazil: Kyanite*	5
Europe:	
France: Andalusite	60
Germany, Federal Republic of:	
Synthetic mullite ¹	15
Spain: Andalusite	5
Sweden: Kyanite	25
United Kingdom:	
Synthetic mullite	10
Other countries	200
Total	315
Africa:	
South Africa, Republic of:	
Andalusite*	320
Sillimanite*	3
Zimbabwe: Kyanite	2
Total	325
Asia:	
China: Unspecified	3
India:	
Kyanite	38
Sillimanite	15
Total	56
Japan:	
Synthetic mullite*	40
Total	99
Oceania:	
Australia:	
Kyanite*	1
Sillimanite*	1
Total	2
World total ^{1 2}	745

*Estimated. Revised. W Withheld to avoid disclosing company proprietary data.

¹Excludes U.S. kyanite and synthetic mullite.

²Data do not add to total shown because of independent rounding.

TABLE 5
KYANITE: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ² and commodity	1987	1988	1989	1990	1991 ³
Australia:					
Kyanite ⁴	³ 1,079	500	500	750	800
Sillimanite ⁴	77	64	⁷ 70	¹ 100	100
Brazil: Kyanite ⁴	^r ³ 731	^r ³ 742	1,000	1,000	1,000
China: Unspecified ⁴	2,500	2,500	2,500	2,500	2,500
France: Andalusite ⁴	³ 50,000	50,000	50,000	50,000	50,000
India:					
Andalusite	122	—	—	—	—
Kyanite	39,959	35,773	⁴ 40,009	³ 38,319	39,000
Sillimanite	12,756	15,377	16,117	¹ 17,072	17,000
Kenya: Kyanite ⁴	1	1	1	1	1
Korea, Republic of	85	112	19	² 20	20
South Africa, Republic of:					
Andalusite	² 218,560	259,556	² 284,617	² 283,677	³ 207,137
Sillimanite	1,243	781	170	² 256	³ 422
Spain: Andalusite	3,916	3,360	³ 3,500	³ 3,600	3,600
Sweden: Kyanite ⁴	5,000	⁶ 6,000	⁶ 6,000	⁶ 6,000	6,000
United States:					
Kyanite	W	W	W	W	W
Mullite, synthetic	W	W	W	W	W
Zimbabwe: Kyanite	1,834	1,795	1,869	¹ 1,800	1,800

¹Estimated. ²Revised. W Withheld to avoid disclosing company proprietary data.

³Owing to incomplete reporting, this table has not been totaled. Table includes data available through Apr. 10, 1992.

⁴In addition to the countries listed, a number of other nations produce kyanite and related materials, but output is not reported quantitatively, and no reliable basis is available for estimation of output levels.

⁵Reported figure.

⁶In addition, about 7,000 metric tons of sillimanite clay (also called kaolinized sillimanite) is produced annually containing 40% to 48% Al₂O₃.

LEAD

By William D. Woodbury

Mr. Woodbury, a physical scientist with the U.S. Bureau of Mines, Branch of Metals, had 25 years of mining and civil works geotechnical experience upon becoming the Bureau's lead specialist in 1982. Domestic survey data were prepared by Eraina Dixon and Lisa Conley, mineral data assistants; international data were prepared by Theodore Spittal and Virginia Woodson, international data coordinators.

Lead is a soft, heavy metal, the most corrosion resistant of the common metals, and one of the oldest metals used by man. Among the nonferrous metals, in terms of tonnage, demand for lead is surpassed only by demand for aluminum, copper, and zinc. Some historians have theorized that the downfall of the Roman Empire was expedited by the debilitating effects on its citizens of drinking water carried in lead pipes. Buildings built in Europe four centuries ago still stand under their original lead roofs. Today's major use of lead is in lead-acid storage batteries. The electrical systems of vehicles, ships, and aircraft depend on such batteries for startup, and in some cases, batteries provide the actual motive power. Other batteries provide standby electrical power for emergencies, and very large lead-acid systems are designed to provide "peaking" power in such applications as commercial power networks and subway systems. An increasing use is in the uninterruptible power supply systems necessary for voltage control and emergency power in critical computer storage systems. Lead in gasoline, once the second largest use of lead in the United States, has been virtually phased out to eliminate the health hazard it was found to present. Some nontransportation uses of lead include increasing use for soundproofing in office buildings, schools, and hotels and earthquake shock dampening in building foundations. It is widely used in hospitals to block X-ray and gamma radiation and is employed to shield against nuclear radiation both in

permanent installations and when radioactive source material is being stored and/or transported.

After 7 consecutive years of significant growth, world demand for lead peaked at more than 6 million metric tons in 1989, but dropped by almost 450,000 tons during 1990 and 1991 as the world economy entered recession. World lead refinery production declined by almost 200,000 tons in 1991, in spite of continuing near-record secondary production in some countries, including the United States. For many years prior to 1983, primary metal demand represented about 60% of the total but gradually declined to about 55% in recent years. This trend is expected to continue with the continuously evolving worldwide environmental consciousness and less dissipation in the end-use pattern. World mine production of lead in 1991 leveled off or declined slightly in most countries, including the United States, with only Australia, China, and Peru reporting marginal increases. Total domestic refinery production in 1991 declined by about 100,000 tons from that of 1990, demand was off by about 30,000 tons, and stocks were rationalized precipitously. World and North American average prices at yearend were about 4 cents per pound below yearend 1990, after slight yearend recoveries. In the United States, prices bottomed in June, but on the London Metal Exchange (LME) the decline was gradual through November. The average spread between the two was 8.2 cents per pound compared with about 9 cents per pound in

1990, still attractive for domestic importation in spite of the decreased demand.

DOMESTIC DATA COVERAGE

Domestic data for lead are developed by the U.S. Bureau of Mines from five voluntary surveys. Typical of these are the combined secondary producer and consumer surveys, both monthly and annual. Of the 208 consuming companies to which a survey request was sent, 184 responded, representing 97% of the total U.S. lead consumption shown in tables 1, 9, 10, 11, 12, and 13. Of the 42 companies and/or plants producing secondary lead, exclusive of copper base, to which a survey request was sent, 33 responded, representing 87% of the total refinery production of secondary lead, not including that from copper base scrap, shown in tables 1, 6, 7, and 8. Production and consumption for the nonrespondents were estimated using prior-year levels adjusted for general industry trends.

BACKGROUND

Geology

Besides being a major user of lead, the United States is a major mine producer and by far the world's leading metal producer. Missouri is by far the main producing State. The leading foreign mine producers, with output similar to that of the United States, are Australia, China, and the U.S.S.R. The leading

metal producers behind the United States are the U.S.S.R., the United Kingdom, the Federal Republic of Germany, and Japan. These five account for about one-half of the world's refined lead production, including secondary.

The minerals in lead ores are relatively simple, with the sulfide galena (PbS) being the major mineral. Most lead deposits contain galena associated with sphalerite (ZnS), pyrite (FeS₂), chalcopyrite (CuFeS₂), and other base metal sulfides or sulfosalts, some of which are recovered to yield byproducts or coproducts, most commonly zinc and silver. Galena usually contains variable amounts of silver also (argentiferous galena). Most sphalerite has associated cadmium, in quantities from traces to 2%, and small quantities of germanium, gallium, indium, and thallium. Lead deposits are of four types: massive sulfide, replacement, contact metamorphic, and vein.

Massive sulfide deposits of lead and zinc have two basic forms of ore body control: sedimentary-structural and volcanogenic-stratabound. The former, known also as Mississippi Valley Type (MVT) deposits, include presently producing areas such as Missouri's Viburnum Trend, Canada's Pine Point District and the Polaris Mine, both in the Northwest Territory, and the Laisvall District of Sweden. The Polaris Mine, well north of the Arctic Circle near the Magnetic North Pole, is the world's most northerly producing mine. MVT deposits are hosted in limestone-dolomite sequences, karst controlled, and often have considerable associated collapse brecciation and/or reef control resulting from ancient drainage patterns and/or facies changes. Volcanogenic-stratabound deposits are commonly interlayered with sedimentary rocks and are usually found in older folded and metamorphosed belts. Examples in Canada are the Bathurst Mine in New Brunswick, the Kidd Creek Mine near Timmons, Ontario, and the Sullivan Mine at Kimberley, British Columbia; examples elsewhere are the Broken Hill and Mount Isa Mines of New South Wales and Queensland, respectively, in Australia; and the Kuroko

District of Japan. These deposits are commonly finer grained and more difficult to win the metals from than the pure sedimentary types. The complex strataform volcanogenic deposits of Alaska, such as the rich producing Red Dog and Greens Creek Mines, exhibit some characteristics of both of the above-described massive sulfide types. The actual concentration of the minerals and/or ore body control, however, relate more to the degree of metamorphism associated with folding and thrusting.

Replacement-type deposits of lead and zinc are commonly irregular hydrothermal deposits in carbonate rocks, but some also occur in quartzites or metamorphic rocks. The form and extent of the ore bodies are determined by the structural and stratigraphic elements that localize the replacement activity of the ore-bearing solutions. They include tabular or cylindrical flat-lying bodies called mantos, pipelike structures that cross the bedding, and irregular-branching bedded deposits associated with veins. Typical examples are the Cerro de Pasco Mine in Peru, the Tsumeb Mine in Namibia, the silver-lead district of Central Mexico, and the Leadville and Gilman districts in Colorado.

Veins are the best known type of ore deposits. They are the most obvious and therefore were the first to be exploited by ancient miners. The vein deposits are commonly situated in faults, joints, or formational contacts. They contain an irregular mixture of barren, or gangue, minerals and are generally arranged in pod-shaped deposits or "shoots," 3 to 30 feet long horizontally and extending hundreds of feet vertically or down the dip. Only a small part of U.S. lead production comes from veins, but there are many highly productive vein-type deposits in Europe, Central America, and South America. The silver-lead deposits of the Coeur d' Alene ("Silver Valley") district in Idaho occur in an extensive vein system. Some other productive examples are the Santa Barbara (Chihuahua), Fresnillo (Zacatecas), and Taxco (Guerrero) Mines in Mexico and the German Harz Mountains, Clausthal, and Freiberg deposits.

Contact metamorphic-type deposits are found near igneous intrusions, which have either provided the solutions or emanations creating the deposits, or have altered and rearranged a mineral deposit already present prior to the intrusion. Deposits range in size from small vein systems to massive pods hundreds of feet long. Although many deposits of this type are mined for other metals in the United States, none have produced significant amounts of lead by today's standard and then only as a byproduct. The Kamioka, Obori, Chichibu, and Nakatatsu deposits of Japan are excellent examples of this type. However, only the two Kamioka Mines at Gifu are presently producing.

Toxicity

A major problem with lead in some uses is its toxicity, since accumulation of even minute quantities in the aqueous system of the body can cause permanent brain damage and/or central nervous system disability, liver and kidney damage, and even death. Even the use of lead shot for hunting geese, ducks, and other migratory waterfowl is declining because of lead's toxic effect on the marine-life chain. Lead's toxicity presents problems in producing it as well as in using it, and emissions from lead smelters and refineries are closely regulated, as are worker blood-lead levels and inplant permissible exposure limits in all lead and lead oxide producing, lead-acid battery manufacturing, and other lead products plants. This adds to the cost of producing lead but is necessary to protect both the general public health and the health of lead industry workers.

Most potential adverse health effects resulting from lead overexposure have been known to some degree for many years. However, in recent years, a major issue and controversy has arisen with respect to the determination of an absolute "threshold" level below which no effects occur. The position of the U.S. Environmental Protection Agency (EPA) to date is that none has been clearly demonstrated. This has especially sparked considerable scientific debate in

the case of average blood lead levels (PbB's) and long-term, low-level exposure to lead primarily stored in the nonaqueous body system. Whereas research on lead effects on blood pressure, kidneys, and red blood cells goes back many years, research on physical development, reproductive effects, and carcinogenicity has primarily emerged in the past decade.

Average PbB's in the United States have fallen dramatically in recent years as the use of lead in gasoline has been eliminated and the dangers of exposure to and ingestion and/or inhalation of old slaking paint and dust have been heavily publicized. Adverse health effects clearly associated with lead apparently begin to occur only at levels well above the current national average. The EPA's current average PbB estimate is 4 to 6 micrograms of lead per deciliter ($\mu\text{g}/\text{dl}$) of blood compared with 12.8 in 1980 for the most sensitive population group, pre-school children. New Center for Disease Control (CDC) guidelines published in 1991 call for individual nutritional and educational intervention for children at 15 to 19 $\mu\text{g}/\text{dl}$ levels, although results of several recent studies of lead effects on infant and mental development in this general range are somewhat inconsistent, or at least not universally definitive when including foreign studies. A 10-year followup study completed in 1989 of 104 children who had suffered clinical lead poisoning found no significant association between blood lead and stature development using their nonpoisoned siblings as controls. In addition, a study completed in 1991 measuring the possible adverse effects of low-level lead exposure on growth in pre-school children found no significant adverse effects on size or growth.

Research has shown that long-term lead exposure can cause adverse effects upon male human reproductive functions at high blood lead levels greater than 40 to 50 $\mu\text{g}/\text{dl}$, but comparable data relative to human females is virtually nonexistent. However, concerns have recently arisen over the implications of lead's apparent ability to cross the placenta and affect the fetus. Six studies between 1986 and 1991

were unable to definitively confirm an association between blood lead and decreased birth weight of children born to occupationally exposed workers, but in an earlier study by Dr. Needleman in 1984 there was a suggestion of minor congenital abnormalities, not subsequently confirmed. It has been known for many years that the human skeleton ultimately retains 90% to 95% of the lead in a person. This raises the possibility that such bone lead could be released to the blood as a function of aging or during times of calcium stress such as pregnancy. A 1988 study of almost 3,000 women showed a significant increase in PbB's after menopause, but no osteoporosis data were obtained. Clearly, more research is needed here.

Experimental animal studies have provided convincing evidence for the carcinogenicity of some lead compounds, specifically lead acetates and phosphates, but the massive doses required to produce tumors demonstrates that the carcinogenic potency is weak. Human epidemiological studies on lead and cancer to date are characteristically inconsistent, and none has corrected for smoking, a significant confounding variable. At this time, EPA considers the potency factor of lead sufficiently low enough as not to consider its carcinogenicity potential in establishing risk-based policies.¹

ANNUAL REVIEW

Legislation and Government Programs

In January, a partnership was formed among Chrysler Corp., Ford Motor Co., and General Motors Corp. called The United States Advanced Battery Consortium (USABC). With participation from the Electric Power Research Institute, its purpose is to develop advanced batteries capable of providing future generations of electric vehicles with significantly increased range and performance. In October, USABC signed an agreement with the U.S. Department of Energy (DOE) to jointly research and equally fund a 4-year, \$260 million program to this effect. This substantial commitment of resources, which also

includes facilities, technology, and personnel, by government and industry jointly in a commercial effort is unparalleled, and a first of any kind involving domestic automakers. If successful, the project could become the model for future public-private cooperation to resolve issues affecting energy resources, the environment, and international competitiveness. The International Lead-Zinc Research Organization (ILZRO) is cooperating in the program with respect to possible roles for advanced lead and zinc battery systems.

In April, lead producers and battery manufacturers were approached by the EPA to voluntarily participate in the "33-50 program," a national effort to reduce industrial emissions of toxic substances one-third by 1992 and one-half by 1995. In a related development of good faith by EPA, in May, an administrative stay was placed on the hazardous waste listing for lead slurries generated from control devices on acid gases that are not dedicated to control particulate air emissions. EPA intends in the future to amend and clarify the scope of listing for all nondedicated (to airborne particulates) controls of sludges generated from air pollution devices. Also in May, EPA made the final determination not to regulate primary lead smelter slags as hazardous waste and tentatively proposed to handle them in conjunction with mining wastes in a later ruling pending reauthorization of the Resource Conservation and Recovery Act (RCRA) in 1992. This was the most significant rulemaking affecting the lead industry in 1991. Other legislative amendments to RCRA pending at yearend with respect to lead involved a uniform Federal lead-acid battery recycling bill, and/or mandatory secondary lead content, along with other lead process waste issues. Source reduction bills on both sides of Congress (some reintroduced from 1990 as Toxic Substances Control Act, TSCA, amendments) affecting minor uses of lead in such diverse "markets" as plumbing, solder (except in electronics), food packaging, inks, dyes, cosmetics, paints, pesticides, and toys were still pending at

yearend. During the year, EPA also undertook comprehensive reviews of the National Ambient Air Quality Standard (NAAQS) for lead, primarily to affect smelters, and New Source Performance Standards (NSPS) for secondary lead plants. Both rules were expected to be promulgated in late 1992. At yearend, 37 States had passed battery disposal or mandatory recycling laws, with action initiated in 6 others. In December, a New York State Court judge disallowed negligence and product liability claims filed against paint manufacturers by New York City, ruling that the city had known for years of the dangers of lead-base paint and had filed suit too late.

Issues

Two significant issues involving lead arose in 1991, one coming to a head and being at least partially resolved, the other promising continuing future bitter debates. Firstly, from January through September, a Regulatory Negotiating procedure, initiated by EPA's Office of Pesticides and Toxic Substances (OPTS), was chartered by law to write a uniform Federal battery recycling rule under TSCA. The chartered committee, comprising government at all levels, business (producer and consumer, small and large), labor, retail trade associations, and environmental and/or legal interests worked diligently for 9 months and were close to an agreeable rule, notwithstanding RCRA problems beyond its chartered jurisdiction. However, TSCA requires risk analysis and cost-benefit studies, performed simultaneously in this case, which can demonstrate positive risk benefits. Unable to satisfy this requirement, especially with respect to lead-acid batteries in landfills--the major issue, the procedure was terminated in September as unacceptable for Federal rulemaking. Apparently, illegally disposed of lead-acid batteries are not a provable significant environmental hazard at this time sufficient to justify further Federal controls. Recycling rates determined by Battery Council International (BCI) reached 97.8% in 1990.

The second issue of major significance that emerged in 1991, and that could prove disastrous to the domestic lead industry if consummated, was that of employing a 150% to 250% excise-pollution tax on lead metal to pay for lead-base paint damage mitigation and cleanup. Legislation to this effect was introduced in the House of Representatives in July, the Lead Paint Hazard Abatement Act, as a purely revenue act, the cost of which would wind up being directly passed on to the ultimate consumers. No action had been taken at yearend. However, no one can question the seriousness of the "old lead" problem, and it must be dealt with somehow, being essentially a city problem potentially affecting significant numbers of persons as older houses continue to decay and/or are demolished, creating additional disposal problems. The paradox is that even if the domestic lead system is "sealed and leveled" (imported metal and product content would be equally taxed), there is the danger that the battery industry could be driven offshore because, even with import duties, source metal discounts would eventually be greater along with lower production margins owing to less environmental sensitivity, cheaper labor, etc. Along with exporting jobs, however, the United States would also most likely wind up exporting environmental control as domestic secondary capacity would dry up because most spent batteries would flow out of the country also. In this case, solving one dilemma could create two more, possibly a third because the cheaper batteries would become expensive enough to eventually lead to mostly uncontrolled battery "chop-shop" rebuilders, which would circumvent excise taxes completely, as well as create a potential environmental disaster.

Production

Primary.—The decrease in domestic mine production of lead in 1991 resulted from the announced significant cutback by The Doe Run Co. for the last three quarters in order to bring overall market supply and anticipated demand in better

balance to avoid stock buildups. However, in spite of this decision and the closure of the Bunker Hill Mine in Idaho in January, along with several other temporary shutdowns, significant production increases at other mines, notably Red Dog and Sweetwater, resulted in an overall lesser decrease of about 18,000 tons. As a result, production from Missouri was reduced to about three-quarters of the national total compared with 79% in 1990. Alaska, Idaho, Colorado, and Montana, in order of priority, produced all but 2,600 tons of the balance. The top 10 mines listed in table 4 produced 95% of the total, and the top 15 all but 2,800 tons. In terms of corporate ownership, three entities, The Doe Run Co., ASARCO Incorporated, and the Cominco American-Dresser Inc. partnership, accounted for about 90% of domestic lead mine production.

During 1990 in southeastern Missouri, The Doe Run Co. of St. Louis, the Nation's largest integrated lead producer, operated three mine and mill divisions, Buick, Fletcher, and Viburnum, which consisted of six mines and four mills. The aggregate capacity, including that from the Brushy Creek Mine which remained on care and maintenance in 1991, was 26,300 tons of ore per day according to parent company Fluor Corp.'s annual SEC Form 10-K. On a fiscal year basis ending October 31, 1991, Doe Run mined and milled 3.56 million tons of ore grading 6.08% lead, which was a decline of about 40,000 tons in contained metal from that of 1990. This resulted in metal production at Doe Run's integrated smelter-refinery in Herculaneum, MO, of about 157,000 tons of refined lead for calendar year 1991 compared with about 231,00 tons in 1990. In addition, Doe Run produced and sold 39,000 tons of copper concentrate and 42,000 tons of zinc concentrate in its fiscal year 1991 from its mines. As of October 31, 1991, these mines had proven ore reserves of approximately 71.1 million tons with an average grade of approximately 4.75% lead, according to Fluor's SEC Form 10-K. Approximately 65% of Doe Run's ore is on properties under Federal mineral leases for terms of 10 to 20

years, renewable for 10 years, for which the company pays the Bureau of Land Management a royalty of 5% of the gross value of concentrates produced. Under the State implementation plan for Herculaneum required by the Federal Clean Air Act, as amended, Doe Run in 1991, completed \$17 million of the \$18 million in control projects agreed to. This was expected to contribute to lowered future production costs, as was the 25% cut in employment in April in conjunction with the production cutback. Significant startup costs were also incurred at Doe Run's new secondary plant discussed below. As a result, the company earnings dropped from \$36 million in 1990 to an operating loss of \$4 million in 1991, according to parent company Fluor Corp.'s annual report to stockholders.

Asarco operated two mine and mill complexes in southern Missouri that together produced 94,700 tons of lead in concentrates, compared with 82,500 tons in both 1989 and 1990, according to the company's annual report to the stockholders. This represented 77% of the production of its "integrated" smelter-refinery at Glover, MO, compared with 72% in 1990, a further step toward Asarco's stated goal of full integration for Glover. Another contribution to the company's newly designated Missouri Lead Circuit in 1991 was a 35% expansion of the Sweetwater Mine's "capacity" reflected by a 45% production increase from 31,300 tons of lead in 1990 to 45,300 tons in 1991, according to Asarco. The West Fork Mine continued a production level, as in 1989 and 1990, of about 50,000 tons, about 20% below envisioned "capacity." The Glover facility produced 118,000 tons of lead in 1991 compared with 112,000 tons in 1990 and 108,000 tons in 1989, according to the report. Asarco purchased about one-half of Cominco American Inc.'s half share of the Magmont Mine to supplement Glover's feed. Asarco's refinery at Omaha, NE, which receives the bullion output from its East Helena, MT, smelter, produced 71,000 tons of lead in 1991, compared with 61,000 tons in 1990 and 65,000 tons in 1989. Asarco also received, as

operator, 50% and 37.5% shares, respectively, of the production from the Leadville (CO) and Galena (ID) Mines. At yearend, Asarco reported reserves in Missouri of 20 million tons grading 4.9% lead at Sweetwater and 6.8 million tons grading 5.7% lead at West Fork.

The Magmont Mine at Bixby, MO, a 50-50 joint venture of Cominco American Inc., the operator, and Dresser Industries Inc., was the Nation's second largest lead-producing mine in 1991, in spite of being only 2 to 3 years from exhaustion. According to parent company Cominco Ltd.'s (Canada) annual report to stockholders, continued exploration yielded no new ore body extensions and added very little additional reserves. However, about 454,000 tons was added to total reserves through block adjustments after mining exceeded original reserve estimates, and sophisticated engineering continued to increase the number of pillars, an increasing share of production, available for recovery. Magmont continued to plan for eventual near-term shutdown. In 1991, Magmont milled 1,019,000 tons of ore grading 6.5% lead compared with 984,000 tons at 7.1% and 962,000 tons at 6.8% in 1990 and 1989, respectively. This yielded 83,000 tons of concentrate grading a record 78.3% lead compared with 87,000 tons at 78.0% and 81,000 tons at 77.9% concentration in 1990 and 1989, respectively. The mine also produced 8,500 tons of zinc in concentrate from 1.0% ore and 1,260 tons of copper from 0.2% ore (1,460 tons from 0.3% ore in 1990--revised). Cominco Alaska's Red Dog Mine, about 90 miles north of Kotzebue in northwest Alaska, had a difficult first full year of production, achieving only slightly more than 75% of anticipated capacity for lead. Some ore from the mine proved difficult to treat and experienced lower than estimated recoveries, but modifications to the mill circuits improved performance toward yearend. Lead concentrate production was 69,500 tons grading 57.2% compared with 372,600 tons of zinc concentrate grading 57.1%. The mill also produced a bulk concentrate of 31,000 tons grading 20.9% lead and

32.8% zinc. Ultimate average annual production levels are projected to be 70,000 tons for lead and 325,000 tons for zinc contained from measured and indicated reserves of 59.7 million tons at yearend of ore averaging 5.5% lead and 18.4% zinc (60.8 million tons end of 1990--revised). (See tables 2 through 5.)

Secondary.—Domestic secondary production in 1991 decreased after 5 consecutive years of growth, as capacity utilization was only about 80%. However, this was primarily the result of a significant net capacity increase for the year (largely to be offset by a major closing early in 1992). In the last quarter of the year, Doe Run's 54,000-ton-per-year state-of-the-art Resource Recycling plant, known as the Buick facility, came on-stream at Boss, MO, and produced successfully at near capacity. At midyear, Tejas Resources, a subsidiary of Powerlab Inc., a major lead oxide manufacturer, came on-stream with a 27,000-ton-per-year capacity, "just-in-time" secondary lead smelter-refinery; i.e., batteries broken elsewhere with no on-site storage. Also at midyear, Roth Brothers Smelting Corp., a nonbattery processor, closed its 10,000-ton-per-year-capacity plant at East Syracuse, NY. During the year, several smaller but similar type producers also closed, primarily a result of being overcome by too low margins (low metal prices versus high scrap prices) combined with continuously tightening emission and workplace standards. At yearend, the secondary lead industry was composed of 16 companies that operated 23 battery breakers-smelters with capacities of 10,000 to 120,000 tons per year. Also operating were five smaller operations, including Asarco's Omaha, NE, refinery, with furnace and kettle capacities from 6,000 to 10,000 tons per year, that did not process batteries. In addition, 14 small companies with 15 plants of less than 1,000 tons per year each of capacity were producing mainly specialty alloys for such uses as solders, brass or bronze ingots, and bearing metals, etc. The combined capacity, including Roth Bros., for the latter two sectors; i.e., "non-

battery smelters," was 56,000 tons, and production was about 44,000 tons, including that of Roth Bros. Total domestic secondary lead production capacity at yearend was estimated to be 1.10 per year compared with 1.03 (revised) million tons at yearend 1990, when that sector produced at about 90% of capacity. In February, Asarco and MIM Holdings Ltd. of Australia announced jointly that they were considering entering the secondary smelting business in the United States, possibly utilizing MIM's "Isasmelt" process. Reportedly, they were looking at locations in the southeast. Later in the year, MIM successfully brought on-stream a similar plant at its subsidiary, Britannia Refined Metals, in Northfleet, the United Kingdom. A decision was expected in 1992. (See tables 6 through 8.)

Consumption

Reported consumption of lead declined by almost 30,000 tons in 1991 compared with that of 1990, mostly in battery offtake and the cessation of lead gasoline additive production in midyear. Lead used in construction remained about level for the sixth consecutive year, but lead oxides used for glass, paint, ceramics, and other chemicals increased after declining for 6 consecutive years, primarily owing to the continuing high demand for video tubes. Most other uses increased or decreased marginally, although lead for bearing metals declined by 30%, a reflection of the continuing recession, but also probably owing to some new alloy substitutions because of lead recycling problems. The latter conditions also prevailed in the case of the 2,000-ton decline for lead used in solder in 1991. Although apparent consumption indicated a decline of 70,000 tons in 1991 compared with that of 1990, the 2-year total is about the same as that for reported consumption. This is explained by the significant production decrease in 1991, forcing the consumer to draw down stocks, in concert with high last quarter 1990 metal imports not reaching the consumer until the first

quarter in 1991. (See tables 9 through 14.)

The Battery Council International (BCI) reported starting-lighting-ignition (SLI) battery production of 77.81 million units in 1991 compared with 79.61 million units in 1990. At an estimated average lead content for all the several classes of about 23 pounds per unit, that sector's offtake was about 812,000 tons. Extrapolated from partial reported data to the U.S. Bureau of Mines, the industrial (stationary)-traction(motive) power sector was estimated to have consumed 185,000 tons of lead, an increase of 13,000 tons over 1990's estimate. Consumer batteries; i.e., small, sealed lead-acid (SLA) cells for flashlights, toys, powertools, lawn mowers, floor polishers, etc., were estimated to have consumed the balance, about 10,000 tons. According to BCI, inventories of SLI batteries at yearend stood at 8.49 million units compared with 9.49 million units at yearend 1990, still well over a 30-day supply. The more than 18% offtake of total battery lead by the industrial and traction sector was the highest since 1986 when it was just less than 20%. The industrial and traction battery sector includes uninterruptible power supply (UPS) designed to ensure constant voltage for large computer systems at hospitals, banks, communication networks, etc., and standby power supply (SBS) for emergency lighting and some telephone systems. About one-third of the lead total in this category applies to electric vehicles and submarines, including some surface boats and some in-plant and mine equipment. The whole industrial-traction sector exhibits great potential for continued future growth as networking of computers of all capacities continues to grow, probably the most significant factor in 1991, and general purpose electric vehicles and customer load-leveling loom ever closer to universal application. As evidence of this growth to date, in 1982 this sector consumed only 67,900 tons of lead, which represented less than 10% of the total lead consumed for batteries.

World Review

According to the International Lead and Zinc Study Group (ILZSG) statistics, consumption of soft and antimonial lead in the market economy countries (MEC) declined slightly in 1991 to 4.46 million tons, compared with 4.48 million tons in 1990 and 1989's record of 4.58 million tons.² Comparable world total apparent consumption of lead in all forms for those years was 5.60, 5.79, and 6.05 (record) million tons, respectively. The significant disparity between the dropoffs in the two data sets obviously reflects the serious economic disruptions resulting primarily from Eastern European geopolitical restructuring during the period. This also resulted in revising downward the estimated world refinery production and consumption data totals for 1990 by over 100,000 tons each. According to ILZSG, exports of refined lead from the former "Soviet bloc," including China and North Korea, to the MEC's declined from more than 100,000 tons in 1990 to about 60,000 tons in 1991, about one-half from the former U.S.S.R. in both years. Refinery production in the former "Soviet bloc" European States, excluding Poland, declined from 950,000 tons in 1989 to an estimated 760,000 tons in 1991, also a reflection in general of the worldwide recession. Although world total refinery production declined 330,000 tons during this period, the secondary sector declined only 100,000 tons and continued to increase its "market share" as end uses of lead continued to become less dissipative along with a growing environmental sensitivity to encourage recycling everywhere. At yearend, world stocks of lead metal had increased marginally from yearend 1990, representing a normal 30-day supply, as supply and demand were in good balance owing to the aforementioned rationalizations. The world price (LME average cash) for 1991 was 3 cents per pound lower than that for December 1990, but for the year was 11.8 cents per pound lower than 1990's average. Compared to the December 1990 average price of 28.3 cents per pound, the price at the low point of 1991

after continual decline was 23 cents for November, rising only to an average of 24.1 cents in December. (See tables 15, 16, and 19.)

Mine Capacity.—There was a net loss of world mine capacity in 1991 of about 75,000 tons, mostly in Europe, as several small mine closings occurred in Bulgaria, Finland, France, Italy, and Sweden, and three major closings in Spain, only slightly offset by a small mine opening in Portugal. In the major producing countries there was a large-scale opening, the Hajar Mine in Morocco; a major reopening, the Sa Dena Hes Mine (formerly Mount Hundere) in the Canadian Yukon Territory; and major capacity reductions at Broken Hill and Elura, New South Wales, Australia.

Mine closures in Ontario (Lyon Lake) and Nova Scotia (Gays River) in Canada mostly offset the new capacity there; a capacity increase at the Thalanga Mine in Queensland along with the opening of the Currawong open pit mine in New South Wales mostly offset the capacity decrease in Australia. In Asia, the long awaited opening of the major Rampura-Agucha open pit mine in Rajasthan, India, was offset slightly by a small mine closing in Japan. In the United States, the Bunker Hill Mine in Idaho closed as the new Van Stone Mine in Washington came on-stream. However, production at the latter was temporarily suspended for economic reasons along with the Ward Mine in Nevada, the Butte Hill Mine in Montana, the Star Mine in Idaho, and the Sunnyside Mine in Colorado, all shut down by yearend. World lead-producing mines operated at 84% of capacity in 1991, the same as in that of 1990, although estimated production decreased by 68,000 tons. Production decreases occurred in Bulgaria, Mexico, the former U.S.S.R., the United States, and Yugoslavia, totaling about 84,000 tons for those major producing countries. Increases estimated to total about 30,000 tons occurred in the major producing countries of China and Peru. (See tables 17 and 18.)

Metal Capacity.—World smelter and refinery capacities during 1991 were somewhat rationalized relative to mine capacity, mostly "environmental retrofitting" and subsequent reratings resulting in increased efficiencies at many plants. Only in Bulgaria were there major closings, that of two smelter-refineries at yearend. At Boss, MO, the Buick facility started operations as a secondary plant, although part of the capacity is theoretically available for primary throughput if needed. In the Federal Republic of Germany, the Imperial Smelting Furnace (ISF) at Duisburg increased capacity by 8,000 tons, and at Binsfeldhammer a new 100,000-ton-per-year QSL smelter came on-stream to replace the existing conventional smelter rated at 80,000 tons. A new ISF plant and refinery also opened at Chanderya in India. In Australia, a new Isasmelt plant, rated at 60,000 tons per year, came on-stream at Mount Isa, Queensland, adding 30,000 tons after partial derating of the existing plant. Secondary capacity worldwide continued to increase as new plants totaling 162,000 tons came on-stream in France, the Federal Republic of Germany, India, the United Kingdom (world's first Isasmelt secondary), and the United States. However, there was a major closing of a 50,000-ton-per-year rated capacity smelter at Elswick, Newcastle, in the United Kingdom. The refinery continued in operation as an alloy-remelter similar to the Alco Pacific plant in Carson, CA. (See table 17.)

Reserves.—Worldwide reserves of lead contained in demonstrated resources from both producing and nonproducing deposits estimated to be economically viable at yearend realized commodity prices were estimated at 68 million metric tons (Mmt) by the U.S. Bureau of Mines. For the largest producers among the MEC's, Australia and the United States contained about 10 Mmt each and Canada 7 Mmt, compared to about 15 Mmt for the countries of the former U.S.S.R. and China combined. Estimated average grades among major MEC producers

ranged from about 6% in Australia to about 1% in Mexico and Spain, compared with a little under 3% in the United States and about 2.5% for demonstrated resources of all of the MEC's, including the United States. No definitive average grade data are available for the former U.S.S.R. or the Asian centrally planned economies. At current production levels and extraction efficiency, these data would indicate a recoverable metal supply of 16 to 17 years. However, marginal economic deposits, measured and indicated, would extend the "reserve base" to 125 million metric tons at somewhat less extraction efficiency on average. In this category, Australia would clearly dominate at an estimated total of 35 Mmt, followed by the United States at 22 Mmt.

In a significant exploration development during 1991, BHP Minerals announced at yearend the discovery of a new polymetallic deposit in Queensland, Australia, called Cannington, with identified reserves to date exceeding 20 million tons of ore grading 10.2% lead. BHP, operator of the Cadjebut Mine in Western Australia, owns a 58% share of the deposit. At the start of the year, CRA Ltd. announced the results of 1990 drilling at the Century deposit, also in Queensland. Reserves were estimated in two zones of 70 million tons each grading 2% lead-7% zinc and 1% lead-13% zinc. Another future, potentially significant addition to reserves was a large lead-zinc discovery announced in the first quarter by Enterprise Nationale de Recherche Minière in Algeria of about 200 million tons of ore at Azrou N' Bechar in the Amizour region. In a potential resource development for the late 1990's, Ivernia West Corp. increased inferred reserves at the Lisheen deposit in County Tipperary, Ireland, from 9.3 million tons to 13.5 million tons grading 2.1% lead and 12.4% zinc. The project is a joint venture with Chevron Mineral Corp. of Ireland. (See table 17.)

Current Research

The U.S. Bureau of Mines is assisting the EPA in the development of treatment

methods to decontaminate lead wastes at several Superfund sites. Interagency agreements have been signed for the cleanup of two former scrap battery processing sites in Ohio, and the characterization and treatment studies on the battery casings and soils from these were completed in 1991. An alternate soil treatment process is being developed that will also meet the criteria that cleaned materials; i.e., soils to be disposed of on-site, qualify for nonhazardous disposal at significantly lower cost than hazardous offsite disposal of the uncleaned mixed materials. By EPA criteria, the material must contain less than 210 ppm lead and meet its Toxic Characteristic Leaching Procedure (TCLP) or Extraction Procedure (EP "Tox") tests. Late in the year a meeting was held to review the conceptual flowchart design for the U.S. Army Corps of Engineers' contractor for final design of the on-site plant system.

The typical lead wastes from such older abandoned battery-breaker sites are ebonite casings and soil and some contaminated polypropylene (less than 10% of modern domestic battery casings are ebonite). The contaminants are lead sulfate, lead oxides, and lead metal, the processing of which involves five steps: water wash, separation, size reduction, carbonation, and acid wash. Step one employs any device supplying tumbling action while washing so that adhering sulfate sludge does not become subsequently embedded in size reduction of the screened minus 4-inch casing wastes. The sludge then passes through an 18-mesh screen for smelting or leach-electrowinning. The separation step involves screening (3 to 4 sizes) of the minus 4-inch casing wastes and air or water elutriation with final separation into plus and minus 3/8-inch fractions. In step three, the plus 3/8-inch casing waste is reduced to minus 3/8-inch by granulator, hammer mill, or shredder, and combined with that from step two for carbonation (step four); sodium and ammonium carbonates work equally well. After rinsing, the minus 3/8-inch carbonated casing wastes are washed in a dilute acid solution. Nitric, acetic, and

fluosilicic acids were all tested successfully (step five). Dissolution of the lead carbonate generates carbon dioxide, resulting in a scrubbing action that removes the remaining lead from any fissures. The leachate can then be processed by electrowinning to recover metallic lead.³ An alternative method of direct slurry electrolysis combining washing and electrowinning in one step for soil treatment showed great promise experimentally. As metallic lead was removed at the cathode, the fluosilicic acid employed was regenerated without loss by adsorption on the soils processed. The U.S. Bureau of Mines future efforts are being directed to adopting the process to remove and recover lead from other sites, such as mine wastes, mill tails, foundry sands, and flue dusts.

A comprehensive coverage of lead-related investigations and an extensive review of current world literature on the extraction and uses of lead and its products were published in quarterly issues of Leadscan, published by the Lead Development Association, London, United Kingdom.

OUTLOOK

Although domestic demand for lead grew on average about 4% per year from 1985 to 1989 (table 10), this rate cannot be sustained in the future because some end uses of lead will be curtailed or eliminated entirely by legislation and/or source reduction, one of the current pollution prevention regulatory strategies. Use of lead in nongrowth markets such as solders, paints, and coatings (already eliminated in interior house paints), ceramics, gasoline additives, containers or other packaging (including inks or dyes, especially where food is concerned), and cosmetics will certainly be affected. Some reduction of lead per battery unit can also be anticipated as the technology continues to advance. As a result, U.S. annual growth in lead demand will probably fall within a range of 0.5% to 1.5% per year in the decade of the nineties, averaging about 1%, as the storage battery sector becomes even more dominant. The lower growth rate

can certainly be expected if source reduction is applied to the ammunition sector, currently the third largest end use. The higher growth rate could be attained if the use of lead-acid batteries for peak-power, load-leveling applications becomes widely accepted for households and commercial facilities and/or there is a moderate demand for private, general purpose electric cars. The latter two conditions will probably not prevail until the end of the century or early in the 21st century.

World demand for lead grew at an average rate of more than 2% through 1989 from the low recession year of 1982 (table 16). Lower growth in U.S. demand, which is currently 22% of the total, will undoubtedly lower the overall world growth rate somewhat in the future. However, storage battery use in all applications will certainly grow faster in the rest of the world than in the United States as some poorer nations increase their living standards while they grow with the world economy. It is estimated that currently about 60% of world demand is for batteries, compared with about 80% in the United States, and is forecast to reach about 70% by the end of the decade as the rest of the world's supply-demand pattern is rationalized by environmental concerns. Therefore, the most probable world growth in lead use until the end of the century is forecast to average about 1.5% per year once the world's economy recovers from the evident recession of 1991-92.

The attendant worldwide production outlook is interrelated with anticipated structural changes. Because of large capital demand and high costs associated with environmental concerns, large production surpluses in the near term are not likely. High realized producer prices are critical to profitably amortizing the large improvement expenditures anticipated over the next 10 years. However, this will continue to be partially subjected to developing situations in zinc and silver markets because of the geologic relationships of the three metals in the primary production sector. The trend of increasing secondary share of production and consumption exhibited in

tables 19 and 16, respectively, is expected to continue until optimum recycling is achieved. Complex multinational, multifaceted realignments and restructuring, including divestitures, among world lead producers and product manufacturers are expected to continue through the rest of the century. Most noticeable will be investments of primary producers, in many cases through acquisitions and mergers, in secondary lead production to protect existing market share.⁴

¹Center for Information on Toxicology and Environment, Durham, NC. A Review of Blood Lead Trends and Health Effects, Apr. 1992, 8 pp. Prepared for Lead Industries Assoc., Inc., New York, NY.

²International Lead and Zinc Study Group (London). Lead and Zinc Statistics. Monthly Bull., v. 32, No. 12, Dec. 1992.

³Cole, E. Recovering Lead From Lead-Acid Battery Waste. Presentation at Waste Stream Minimization-Utilization Technology Fair, Apr. 25, 1991, Vienna, VA. Preprints available, U.S. Bureau of Mines Research Center, Rolla, MO.

⁴Woodbury, W. Lead. Ch. in BuMines Minerals Yearbook, 1989, pp. 642-643.

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TABLE 1
SALIENT LEAD STATISTICS

(Metric tons unless otherwise specified)

	1987	1988	1989	1990	1991	
United States:						
Production:						
Domestic ores, recoverable lead content	311,381	384,983	410,915	¹ 483,704	465,931	
Value	thousands \$246,720	\$315,222	\$356,476	¹ \$490,771	\$343,948	
Primary lead (refined):						
From domestic ores and base bullion	336,471	371,348	379,034	385,637	323,851	
From foreign ores and base bullion	37,139	20,739	17,421	18,020	21,863	
Secondary lead (lead content)	710,067	736,401	891,341	¹ 922,197	883,735	
Exports (lead content):						
Lead ore and concentrates	8,764	20,902	¹ 57,038	¹ 56,600	¹ 87,953	
Lead materials, excluding scrap	13,586	29,077	¹ 43,837	¹ 76,749	¹ 113,872	
Imports for consumption:						
Lead in ore and concentrates	873	20,606	¹ 5,122	¹ 10,668	¹ 12,437	
Lead in base bullion	10,827	4,046	¹ 5,782	¹ 2,713	¹ 419	
Lead in pigs, bars, and reclaimed scrap	192,260	155,893	¹ 116,358	¹ 90,919	¹ 116,590	
Stocks, Dec. 31:						
Primary lead ²	21,608	15,398	15,623	25,525	9,089	
At consumers and secondary smelters	88,586	¹ 89,867	¹ 82,356	¹ 86,340	72,030	
Consumption of metal, primary and secondary	1,230,373	1,245,170	1,277,604	¹ 1,275,226	1,246,337	
Price: Metals Week average, delivered, cents per pound	35.94	37.14	39.35	46.02	33.48	
World:						
Production:						
Mine	thousand metric tons	³ 3,352.4	³ 3,358.6	³ 3,285.4	³ 3,390.1	³ 3,318.3
Refinery ³	do.	³ 3,192.9	³ 3,219.7	³ 3,264.6	³ 3,129.5	³ 3,028.9
Secondary refinery	do.	² 2,529.1	² 2,596.1	² 2,707.2	² 2,700.6	² 2,613.4
Price: London Metal Exchange, pure lead, cash average, cents per pound		26.99	29.73	30.63	37.05	25.30

¹Estimated. ²Revised.

³Because of the implementation of the Harmonized Tariff System in Jan. 1989, import and export categories for 1989, 1990, and 1991 are not necessarily comparable with those in previous years.

²American Bureau of Metal Statistics Inc.

³Primary metal production only; includes secondary metal production, where inseparable.

**TABLE 2
MINE PRODUCTION OF RECOVERABLE LEAD IN THE UNITED STATES, BY STATE**

(Metric tons)

State	1987	1988	1989	1990	1991
Idaho	W	W	W	W	W
Missouri	W	353,194	366,931	380,781	351,995
Montana	W	8,266	W	W	W
Nevada	—	W	—	830	W
New Mexico	W	W	W	W	193
South Dakota	—	—	4	—	—
Total¹	311,381	384,983	410,915	483,704	465,931

¹Revised. W Withheld to avoid disclosing company proprietary data; included in "Total."

¹Includes, for at least some of the years 1987-91, Alaska, Arizona, Colorado, Illinois, New York, and Tennessee.

**TABLE 3
MINE PRODUCTION OF RECOVERABLE LEAD IN THE UNITED STATES, BY MONTH**

(Metric tons)

Month	1990 [*]	1991
January	42,408	41,855
February	39,039	41,437
March	39,850	41,905
April	37,369	38,042
May	40,803	43,843
June	38,803	36,647
July	42,281	47,808
August	47,218	41,339
September	37,905	36,361
October	42,979	39,233
November	38,499	28,185
December	36,550	29,276
Total	483,704	465,931

^{*}Revised.

TABLE 4
TWENTY-FIVE LEADING LEAD-PRODUCING MINES IN THE UNITED STATES IN 1991, IN ORDER OF OUTPUT

Rank	Mine	County and State	Operator	Source of lead
1	Fletcher	Reynolds, MO	The Doe Run Co.	Lead-zinc ore.
2	Magmont	Iron, MO	Cominco American Inc.	Do.
3	Buick	do.	The Doe Run Co.	Do.
4	Red Dog	Northwest Arctic, AK	Cominco Alaska Inc.	Zinc ore.
5	West Fork	Reynolds, MO	ASARCO Incorporated	Lead-zinc ore.
6	Sweetwater	do.	do.	Do.
7	Casteel ¹	Iron, MO	The Doe Run Co.	Copper-lead ore.
8	Lucky Friday	Shoshone, ID	Hecla Mining Co.	Lead-zinc ore.
9	Viburnum No. 29	Washington, MO	The Doe Run Co.	Do.
10	Greens Creek	Admiralty Island, AK	Greens Creek Mining Co.	Zinc ore.
11	Montana Tunnels	Jefferson, MT	Montana Tunnels Mining Inc.	Do.
12	Leadville Unit	Lake, CO	ASARCO Incorporated	Do.
13	Viburnum No. 28	Iron, MO	The Doe Run Co.	Lead-zinc ore.
14	Sunnyside	San Juan, CO	San Juan County Mining Venture	Do.
15	Van Stone	Stevens, WA	Equinox Resources	Zinc ore.
16	Galena	Shoshone, ID	ASARCO Incorporated	Silver ore.
17	Balmat	St. Lawrence, NY	Zinc Corporation of America	Zinc ore.
18	Ward/Taylor	White Pine, NV	Alta Gold Co.	Lead-zinc ore.
19	Troy Unit	Lincoln, MT	ASARCO Incorporated	Copper ore.
20	Butte Hill	Silver Bow, MT	New Butte Mining Co. Inc.	Lead-zinc ore.
21	Mission	Pima, AZ	ASARCO Incorporated	Copper ore.
22	Pierrepoint	St. Lawrence, NY	Zinc Corporation of America	Zinc ore.
23	Center	Grant, NM	Mount Royal Mining Co.	Gold ore.
24	Sunshine	Shoshone, ID	Sunshine Mining Co.	Gold-silver ore.
25	St. Cloud	Sierra, NM	Gold Fields Mining Corporation	Copper ore.

¹Includes Bruaty Creek Mill.

TABLE 5
REFINED LEAD PRODUCED AT PRIMARY REFINERIES IN THE UNITED STATES, BY SOURCE MATERIAL¹

(Metric tons unless otherwise specified)

Source material	1987	1988	1989	1990	1991
Refined lead:					
Domestic ores and base bullion	336,471	371,348	379,034	385,637	323,851
Foreign ores and base bullion	37,139	20,739	17,421	18,020	21,863
Total	373,610	392,087	396,455	403,657	345,714
Calculated value of primary refined lead ²	thousands \$296,026	\$321,039	\$343,932	\$409,537	\$255,174

¹Total refined lead: American Bureau of Metal Statistics Inc.; domestic and foreign ores: U.S. Bureau of Mines calculations.

²Value based on average quoted price.

TABLE 6
STOCKS AND CONSUMPTION OF NEW AND OLD LEAD SCRAP IN THE
UNITED STATES, BY TYPE OF SCRAP

(Metric tons, gross weight)

Type of scrap	Stocks, Jan. 1	Receipts	Consumption			Stocks, December 31 ¹
			New scrap	Old scrap	Total	
1990						
Smelters, refiners, others:						
Soft lead ²	1,028	'28,096	—	'27,737	'27,737	'1,385
Hard lead	191	7,116	—	'6,541	'6,541	'767
Cable lead	1,021	'15,872	—	'15,731	'15,731	1,161
Battery-lead	'24,362	'1,029,855	—	'1,025,525	'1,025,525	'28,693
Mixed common babbitt	196	748	—	752	752	192
Solder and tinny lead	1,835	'30,812	—	'30,827	'30,827	'1,820
Type metals	106	'4,600	—	'4,617	'4,617	90
Drosses and residues	'1,385	'61,247	'60,489	958	'61,447	'1,184
Total¹	'30,123	'1,178,347	'60,489	'1,112,688	'1,173,177	'35,293
1991						
Smelters, refiners, others:						
Soft lead ²	1,385	20,296	—	21,162	21,162	519
Hard lead	767	6,201	—	6,561	6,561	406
Cable lead	1,161	24,694	—	24,915	24,915	941
Battery-lead	28,693	950,812	—	959,571	959,571	19,934
Mixed common babbitt	192	729	—	729	729	192
Solder and tinny lead	1,820	9,307	—	9,182	9,182	1,945
Type metals	90	7,368	—	7,392	7,392	66
Drosses and residues	1,184	69,960	67,758	1,675	69,433	1,712
Total¹	35,293	1,089,366	67,758	1,031,186	1,098,944	25,715

¹Revised.

¹Data may not add to totals shown because of independent rounding.

²Includes remelt lead from cable sheathing plus other soft lead scrap processing.

TABLE 7
SECONDARY METAL RECOVERED¹ FROM LEAD AND TIN SCRAP IN
THE UNITED STATES

(Metric tons)

	Lead	Tin	Antimony	Other	Total ²
1990					
Refined pig lead ³	461,409	—	—	—	461,409
Refined pig tin ⁴	—	186	—	—	186
Lead and tin alloys:					
Antimonial lead	425,413	739	15,018	737	441,906
Lead-base babbitt	530	28	57	(⁵)	615
Solder	(⁶)	2,876	126	(⁶)	3,002
Type metal	868	46	122	4	1,040
Other alloys, including cable lead	17,778	36	3	—	17,817
Total ²	444,588	3,726	15,326	740	464,379
Tin content of chemical products	—	33	—	—	33
Grand total ²	905,997	3,945	15,326	740	926,007
1991					
Refined pig lead ³	421,907	—	—	—	421,907
Refined pig tin ⁴	—	204	—	—	204
Lead and tin alloys:					
Antimonial lead	426,938	928	12,220	569	440,655
Lead-base babbitt	443	24	50	(⁵)	516
Solder	(⁶)				
Type metal	863	44	121	4	1,031
Other alloys, including cable lead	19,581	2,696	65	8	22,349
Total ²	447,825	3,692	12,454	582	464,552
Tin content of chemical products	—	34	—	—	34
Grand total ²	869,734	3,930	12,454	582	886,697

¹Revised.

²Most of the figures herein represent actual reported recovery of metal from scrap.

³Data may not add to totals shown because of independent rounding.

⁴Includes remelt lead.

⁵Includes remelt tin.

⁶Included with "Antimony" to avoid disclosing company proprietary data.

⁷Included with "Other alloys, including cable lead" to avoid disclosing company proprietary data.

TABLE 8
LEAD RECOVERED FROM SCRAP
PROCESSED IN THE UNITED
STATES, BY KIND OF SCRAP
AND FORM OF RECOVERY

(Metric tons)

	1990	1991
KIND OF SCRAP		
New scrap:		
Lead-base	42,629	48,169
Copper-base	5,471	6,000
Tin-base	4	3
Total	48,104	54,172
Old scrap:		
Battery-lead	785,664	756,461
All other lead-base	77,704	65,102
Copper-base	10,725	8,000
Tin-base	—	—
Total	874,093	829,563
Grand total	922,197	883,735
FORM OF RECOVERY		
As soft lead	461,409	421,907
In antimonial lead	425,413	426,938
In other lead alloys	19,175	20,887
In copper-base alloys	16,196	14,000
In tin-base alloys	4	3
Total	922,197	883,735
Value ¹ thousands	\$935,630	\$652,291

¹Estimated. ²Revised.

³Value based on average quoted price of common lead.

TABLE 9
U.S. CONSUMPTION OF LEAD, BY PRODUCT

(Metric tons)

SIC Code	Product	1990	1991
Metal products:			
3482	Ammunition: Shot and bullets	58,210	58,458
Bearing metals:			
35	Machinery except electrical	W	W
36	Electrical and electronic equipment	199	303
371	Motor vehicles and equipment	W	12,624
37	Other transportation equipment	W	399
	Total bearing metals	5,212	3,669
3351	Brass and bronze: Billets and ingots	9,943	8,997
36	Cable covering: Power and communication	18,253	17,472
15	Calking lead: Building construction	1,688	1,074
Casting metals:			
36	Electrical machinery and equipment	538	W
371	Motor vehicles and equipment	W	W
37	Other transportation equipment	1,996	2,372
3443	Nuclear radiation shielding	W	W
	Total casting metals	14,843	14,141
Pipes, traps, other extruded products:			
15	Building construction	9,281	8,975
3443	Storage tanks, process vessels, etc.	(1)	(1)
	Total pipes, traps, other extruded products	9,281	8,975
Sheet lead:			
15	Building construction	17,534	17,964
3443	Storage tanks, process vessels, etc.	(1)	(1)
3693	Medical radiation shielding	3,479	4,370
	Total sheet lead	21,013	22,334
Solder:			
15	Building construction	4,472	3,651
341/371	Motor vehicles, equipment, metal cans and shipping containers	6,240	5,013
367	Electronic components and accessories	4,040	4,495
36	Other electrical machinery and equipment	1,737	1,592
	Total solder	16,490	14,750
Storage batteries:			
3691	Storage battery grids, post, etc.	571,187	591,884
3691	Storage battery oxides	448,450	415,233
	Total storage batteries	1,019,637	1,007,117
371	Terne metal: Motor vehicles and equipment	(1)	(1)
27	Type metal: Printing and allied industries	(1)	(1)
34	Other metal products ^f	3,812	3,254
	Total metal products	1,178,381	1,160,241
Other oxides:			
285	Paint	W	W
32	Glass and ceramics products	W	W

See footnotes at end of table.

TABLE 9—Continued
U.S. CONSUMPTION OF LEAD, BY PRODUCT

(Metric tons)

SIC Code	Product	1990	1991
	Other oxides—Continued		
28	Other pigments and chemicals	13,500	11,695
	Total other oxides	56,484	59,617
2911	Gasoline additives	(1)	(1)
	Miscellaneous uses ⁸	*40,361	*26,478
	Grand total	*1,275,226	*1,246,337

¹Revised. W Withheld to avoid disclosing company proprietary data; included in appropriate totals.

²Includes "Terns metal: Motor vehicles and equipment."

³Included with "Building construction" to avoid disclosing company proprietary data.

⁴Data do not add to total shown because of independent rounding.

⁵Included with "Bearing metals: Motor vehicles and equipment."

⁶Included with "Other metal products" to avoid disclosing company proprietary data.

⁷Includes lead consumed in foil, collapsible tubes, annealing, galvanizing, plating, and fishing weights.

⁸Included with "Miscellaneous uses" to avoid disclosing company proprietary data.

⁹Includes "Gasoline additives."

TABLE 10
LEAD SUPPLY-DEMAND RELATIONSHIPS¹

(Thousand metric tons)

	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Mine production (Pb in concentrates):														
United States	263	278	301	292	331	477	540	547	585	570	626	587	573	557
Rest of world	2,262	2,418	2,550	2,579	2,681	2,773	2,876	2,871	2,887	2,940	2,811	2,868	2,792	2,808
Total	2,525	2,696	2,851	2,871	3,012	3,250	3,416	3,418	3,472	3,510	3,437	3,455	3,365	3,365
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY														
Components of U.S. supply:														
Refinery production:														
Domestic ore	275	283	299	243	334	481	489	534	531	527	535	483	520	490
Foreign ore	141	103	111	110	107	113	126	70	94	97	85	96	76	62
Old scrap	426	450	440	433	428	468	459	444	452	489	545	512	564	637
Imports—Metal, excluding scrap	193	202	260	331	307	253	222	175	223	162	107	90	129	231
Industry stocks, Jan. 1, pigs and bars	160	137	122	102	117	85	138	210	161	166	136	185	195	157
Government stockpile releases	36	49	58	25	26	20	11	9	41	191	241	6	—	—
Total U.S. supply	1,231	1,224	1,290	1,244	1,319	1,420	1,445	1,442	1,502	1,632	1,649	1,372	1,484	1,577
Distribution of U.S. supply:														
Industry stocks, Dec. 31, pigs and bars	137	122	102	117	85	138	210	161	166	136	185	195	157	135
Exports—Metal, excluding scrap	9	7	5	6	8	4	7	5	8	60	56	19	5	9
Industrial demand	1,085	1,095	1,183	1,121	1,226	1,278	1,228	1,276	1,328	1,436	1,408	1,158	1,322	1,433
U.S. DEMAND PATTERN														
Ammunition	51	52	71	71	75	72	66	79	77	74	79	68	67	62
Construction	131	122	118	108	112	105	90	90	80	79	69	63	65	75
Electrical	80	84	93	88	85	84	80	117	116	122	120	70	75	90
Gasoline additives	203	204	225	225	238	246	253	240	253	249	227	189	218	211
Oxides and chemicals	94	99	109	94	100	93	90	74	82	100	106	72	96	91
Transportation	430	430	460	440	520	580	560	590	630	720	715	625	705	795
Other	96	104	107	95	96	98	89	86	90	92	92	71	96	109
Total U.S. demand	1,085	1,095	1,183	1,121	1,226	1,278	1,228	1,276	1,328	1,436	1,408	1,158	1,322	1,433
Total U.S. primary demand (Industrial demand less old scrap)	659	645	743	688	798	810	769	832	876	947	863	646	758	796
PRICES														
Average annual (cents per pound)	13.6	16.0	15.2	14.0	13.2	14.9	15.7	13.9	15.0	16.3	22.5	21.5	23.1	30.7
Average annual, based on constant 1987 dollars, (cents per pound)	48.6	55.7	50.9	45.9	41.3	44.1	44.0	36.8	38.0	38.8	49.1	42.6	43.2	53.7

See footnotes at end of table.

TABLE 10—Continued
LEAD SUPPLY-DEMAND RELATIONSHIPS¹

(Thousand metric tons)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Mine production (Pb in concentrates):														
United States	'548	'543	573	459	'528	'462	335	424	353	319	394	420	'497	477
Rest of world	2,843	2,925	2,897	2,907	2,918	2,891	2,934	3,007	2,992	3,033	2,965	2,865	2,893	2,841
Total	'3,391	'3,468	3,470	3,366	'3,446	'3,353	3,269	3,431	3,345	'3,352	'3,359	3,285	'3,390	3,318
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY														
Components of U.S. supply:														
Refinery production:														
Domestic ore	504	532	509	443	465	464	324	423	348	336	371	379	386	324
Foreign ore	64	46	39	55	52	55	65	71	22	37	21	17	18	22
Old scrap	650	673	581	578	521	452	586	570	575	658	691	842	874	830
Imports—Metal, excluding scrap	227	183	82	100	95	177	163	133	142	188	152	122	97	122
Industry stocks, Jan. 1, pigs and bars	135	143	199	181	203	171	154	142	178	104	110	105	98	112
Government stockpile releases	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total U.S. supply	1,580	1,577	1,410	1,357	1,336	1,319	1,292	1,339	1,265	1,323	1,345	1,465	1,473	1,410
Distribution of U.S. supply:														
Industry stocks, Dec. 31, pigs and bars	143	199	181	203	171	154	142	178	104	110	105	98	112	81
Exports—Metal, excluding scrap	8	11	164	23	56	20	7	27	13	10	14	34	64	102
Industrial demand	1,429	1,367	1,065	1,131	1,109	1,145	1,143	1,134	1,148	1,203	1,226	1,333	1,297	1,227
U.S. DEMAND PATTERN														
Ammunition	56	53	49	49	44	44	48	50	44	47	53	57	58	58
Construction	60	50	37	37	40	44	43	39	34	31	32	31	34	32
Electrical	88	86	70	74	75	80	93	120	143	138	132	149	143	115
Gasoline additives ²	178	187	128	111	119	89	79	46	29	27	24	24	21	11
Oxides and chemicals	92	91	78	80	61	69	77	73	70	68	63	58	57	60
Transportation	855	815	640	720	720	770	755	760	785	850	875	980	950	920
Other	100	85	63	60	50	49	48	46	43	42	47	34	34	31
Total U.S. demand	1,429	1,367	1,065	1,131	1,109	1,145	1,143	1,134	1,148	1,203	1,226	1,333	1,297	1,227
Total U.S. primary demand (Industrial demand less old scrap)	779	694	484	553	588	693	557	564	573	545	535	491	423	397
PRICES														
Average annual (cents per pound)	33.7	52.7	42.4	36.5	25.5	21.7	25.6	19.1	22.0	35.9	37.1	39.4	46.0	33.5
Average annual, based on constant 1987 dollars, (cents per pound)	54.9	78.9	58.2	45.6	30.1	24.5	27.9	20.2	22.8	35.9	35.9	37.8	'44.0	32.0

¹Estimated. ²Revised.

¹1964-83 revised from previous editions of Mineral Facts and Problems. Mine production data revised from Minerals Yearbooks series.

²1987-91 U.S. Department of Commerce estimates, (domestic production ceased June 1991).

TABLE 11
U.S. CONSUMPTION OF LEAD,
BY MONTH¹

(Metric tons)

Month	1990	1991
January	¹ 107,330	105,605
February	¹ 108,220	109,783
March	114,093	105,411
April	¹ 102,627	105,569
May	¹ 107,787	102,228
June	¹ 104,626	96,036
July	98,715	94,431
August	¹ 114,137	105,945
September	106,059	106,910
October	¹ 113,795	111,870
November	105,228	106,386
December	92,609	96,164
Total ²	¹ 1,275,226	³ 1,246,337

¹Revised.

²Monthly totals include monthly reported consumption plus the prorated monthly distribution for companies that report on an annual basis only.

³Includes lead that went directly from scrap to fabricated products.

⁴Data do not add to total shown because of independent rounding.

TABLE 12
U.S. CONSUMPTION OF LEAD IN 1991, BY STATE¹

(Metric tons)

State	Refined soft lead	Lead in antimonial lead	Lead in alloys	Lead in copper-base scrap	Total ²
Arizona, California, Oregon, Washington	57,024	40,873	8,604	—	106,499
Florida	3,965	6,079	—	—	10,044
Georgia	31,781	5,769	—	—	37,550
Illinois	25,420	38,887	6,569	624	71,500
Michigan	16,321	11,385	—	—	27,706
Missouri	11,765	17,063	—	—	28,828
Ohio and Pennsylvania	111,286	46,079	38,449	2,045	197,857
Texas	83,998	15,413	6,159	—	105,568
Alabama, Arkansas, Louisiana, Mississippi, Oklahoma	22,567	19,745	16,247	2,295	60,854
Colorado, Indiana, Iowa, Kansas, Kentucky, Minnesota, Nebraska, Tennessee, Wisconsin	279,359	98,461	40,930	1,185	419,934
Delaware, Maryland, New Jersey, North Carolina, South Carolina	81,597	42,147	9,622	249	133,613
Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, Vermont	25,773	10,642	9,953	16	46,384
Total ²	750,854	352,543	136,533	6,413	1,246,337

¹Includes lead that went directly from scrap to fabricated products.

²Data may not add to totals shown because of independent rounding.

TABLE 13
U.S. CONSUMPTION OF LEAD IN 1991, BY CLASS OF PRODUCT¹

(Metric tons)

Product	Soft lead	Lead in antimonial lead	Lead in alloys	Lead in copper-base scrap	Total ²
Metal products	58,562	64,425	23,725	6,413	153,124
Storage batteries	610,889	286,700	109,527	—	1,007,117
Other oxides	59,617	—	—	—	59,617
Miscellaneous ³	21,783	1,416	3,279	—	26,478
Total ²	750,854	352,543	136,533	6,413	1,246,337

¹Includes lead that went directly from scrap to fabricated products.

²Data may not add to totals shown because of independent rounding.

³Includes gasoline additives to avoid disclosing company proprietary data.

TABLE 14
STOCKS OF LEAD AT CONSUMERS AND SECONDARY SMELTERS IN
THE UNITED STATES, DECEMBER 31

(Metric tons, lead content)

Year	Refined soft lead	Lead in antimonial lead	Lead in alloys	Lead in copper-base scrap	Total ¹
1987	55,278	27,959	5,185	164	88,586
1988	50,850	34,108	4,756	151	89,867
1989	48,592	28,960	4,564	239	82,356
1990	46,478	34,512	5,132	219	86,340
1991	33,576	33,615	4,649	190	72,030

¹Revised.

¹Data may not add to totals shown because of independent rounding.

TABLE 15
AVERAGE MONTHLY AND ANNUAL QUOTED PRICES OF LEAD¹

(Cents per pound)

Month	1990		1991	
	North American producer price	London Metal Exchange	North American producer price	London Metal Exchange
January	39.81	32.08	34.52	27.20
February	41.84	35.31	33.23	26.90
March	54.11	48.05	33.34	27.32
April	48.73	37.86	33.30	27.22
May	45.21	37.41	32.60	25.16
June	45.16	37.98	32.03	24.90
July	50.13	39.67	32.79	24.84
August	50.36	39.70	32.86	24.49
September	49.47	38.00	33.39	24.47
October	46.15	34.47	34.62	23.67
November	42.75	31.77	34.48	22.95
December	38.52	28.30	34.65	24.12
Average	46.02	37.05	33.48	25.30

¹Metals Week. Quotations for the United States on a nationwide, delivered basis. LME cash average.

TABLE 16
WORLD LEAD SUPPLY AND DEMAND

(Thousand metric tons)

Year	Mine production	Primary demand ¹	Apparent consumption	Stock changes (ILZSG)	Refinery production	Production surplus/deficit	
1978	3,391	60%	5,595	-71	5,524	+91	
1979	3,468		5,650	+62	5,712		
1980	3,470		5,364	+66	5,430		
1981	3,366		5,337	-7	5,330		
1982	3,446		5,174	+41	5,215		
1983	3,353	57.3%	2.25% per year average growth	5,303	-19	5,284	-186
1984	3,269			5,582	-113	5,469	
1985	3,431			5,587	+54	5,641	
1986	3,345			5,603	-52	5,551	
1987	3,352			5,685	+37	5,722	
1988	3,359	54.5%		5,833	-17	5,816	+85
1989	3,285			6,048	-76	5,972	
1990	3,390			5,785	+45	5,830	
1991*	3,318			5,602	+40	5,642	
Total	47,243	57.5%	78,148	-10	78,138	² -10	

*Estimated. †Revised.

¹Recoverable content (95%) of mine production (lead in concentrate) divided by apparent consumption.

²Yearend stocks 1977=468; yearend stocks 1991=458 (estimated; producer, consumer, merchant, LME).

TABLE 17
WORLD LEAD PRIMARY PRODUCTION CAPACITY, ANNUAL

(Thousand metric tons)

	1990			1991		
	Mine	Smelter	Refinery	Mine	Smelter	Refinery
North America:						
Canada	381	210	230	385	210	230
Mexico	210	300	320	213	300	320
United States	759	525	605	751	410	495
Other	10	—	—	11	—	—
Total	1,360	1,035	1,155	1,360	920	1,045
South America:						
Peru	212	115	110	210	115	110
Other	88	110	110	70	110	110
Total	300	225	220	280	225	220
Europe:						
Belgium	—	90	125	—	90	125
Bulgaria*	60	130	120	46	90	90
France	1	190	150	—	150	150
Germany, Federal Republic of	7	210	260	8	235	260
Italy	18	130	100	11	130	105
Poland	50	90	90	42	25	35
Spain	72	90	90	47	90	90
U.S.S.R.*	500	650	830	500	650	830
United Kingdom	—	40	150	—	40	150
Yugoslavia	112	125	125	113	125	125
Other	202	155	120	198	155	120
Total	1,022	1,900	2,160	965	1,780	2,080
Africa:						
Morocco	74	65	65	82	65	65
Namibia	40	75	75	41	75	75
South Africa, Republic of	82	—	—	82	—	—
Other	24	30	15	20	30	15
Total	220	170	155	225	170	155
Asia:						
China*	370	250	250	370	250	250
India	30	30	30	38	65	65
Japan	28	240	315	24	240	315
North Korea*	85	120	110	80	120	110
Other	70	20	55	73	20	55
Total	583	660	760	585	695	795
Oceania: Australia	590	435	235	585	465	235
World total	4,075	4,425	4,685	4,000	4,255	4,530

*Estimated. †Revised.

Sources: International Lead Zinc Study Group, U.S. Bureau of Mines estimates, and other published sources.

TABLE 18
LEAD: WORLD MINE PRODUCTION OF LEAD IN CONCENTRATES, BY
COUNTRY¹

(Thousand metric tons)

Country ²	1987	1988	1989	1990	1991 ³
Algeria ⁴	¹ 1.6	¹ 1.9	¹ 1.4	¹ 1.1	1.2
Argentina	26.1	28.5	26.7	² 23.4	² 23.7
Australia	489.1	465.5	495.0	⁵ 565.0	⁵ 571.0
Austria	5.2	2.3	1.6	1.5	³ 1.2
Bolivia	9.0	12.5	15.7	¹ 19.9	² 20.8
Brazil	11.6	14.3	16.1	¹ 13.7	³ 9.2
Bulgaria ⁴	60.0	60.0	⁵ 57.0	⁵ 57.0	43.6
Burma	4.6	6.0	5.2	⁴ 4.4	4.4
Canada	413.7	368.4	275.0	² 232.1	235.0
Chile	.8	1.4	1.2	1.1	³ 1.1
China ⁴	267.0	312.0	³ 308.0	³ 364.0	380.0
Colombia	.2	(¹)	.4	.3	—
Congo (Brazzaville)	¹ 1.4	1.8	1.0	¹ 1.0	1.0
Czechoslovakia	2.8	² 2.8	2.7	³ 3.0	2.5
Ecuador ⁴	.2	.2	.2	.2	0.2
Finland	² 2.9	1.9	2.6	¹ 1.7	1.3
France	2.2	2.0	1.1	¹ 1.1	1.7
Germany: Western states	18.8	14.3	⁷ 7.7	⁸ 8.6	7.5
Greece	20.6	23.1	² 22.3	² 23.5	24.0
Greenland	20.5	23.1	24.1	¹ 16.0	—
Honduras	5.0	16.9	⁹ 9.6	⁵ 8.8	5.0
India	36.7	30.5	26.5	² 25.1	² 25.1
Iran ⁵	¹ 13.0	¹ 11.0	10.5	⁹ 9.3	³ 12.6
Ireland	33.8	32.5	32.1	35.3	35.0
Italy	12.0	16.5	¹ 17.5	¹ 16.0	16.0
Japan	27.9	22.9	18.6	18.7	³ 18.3
Kenya ⁶	.5	.6	.6	.6	—
Korea, North ⁴	110.0	110.0	120.0	120.0	120.0
Korea, Republic of	14.0	14.5	16.5	¹ 14.9	14.0
Mexico	177.2	171.3	163.0	179.9	³ 157.9
Morocco	75.7	72.2	67.3	⁶ 68.8	73.0
Namibia	33.0	37.2	23.7	² 20.7	11.8
Nigeria	(¹)	(¹)	(¹)	(¹)	(¹)
Norway	3.1	2.8	3.2	3.0	3.5
Peru	204.0	149.0	192.2	189.0	203.0
Poland ⁴	⁴ 8.0	⁶ 4.0	⁶ 6.0	¹ 61.3	60.0
Romania ⁴	² 0.0	¹ 15.0	⁶ 7.0	⁶ 5.0	6.5
South Africa, Republic of	93.6	90.2	78.2	69.4	³ 76.3
Spain	83.3	74.7	62.6	⁶ 1.5	60.0
Sweden	90.4	91.6	89.0	⁸ 4.2	79.0
Thailand	23.5	29.5	25.1	22.2	22.0
Tunisia	3.5	3.7	2.7	³ 3.0	3.0
Turkey	7.3	9.4	¹ 10.6	¹ 9.7	10.0
U.S.S.R.	⁴ 40.0	⁴ 40.0	⁴ 40.0	⁴ 20.0	400.0

See footnotes at end of table.

TABLE 18—Continued

LEAD: WORLD MINE PRODUCTION OF LEAD IN CONCENTRATES, BY COUNTRY¹

(Thousand metric tons)

Country ²	1987	1988	1989	1990	1991 ⁶
United Kingdom	0.7	1.2	² 2.2	¹ 1.4	³ 1.0
United States	318.7	394.0	420.2	⁴ 496.5	³ 476.9
Yugoslavia	¹ 106.7	¹ 103.3	¹ 107.0	⁵ 99.1	90.0
Zambia ⁷	12.5	12.1	⁸ 8.8	⁹ 9.6	9.0
Total	³ 3,352.4	³ 3,358.6	³ 3,285.4	³ 3,390.1	3,318.3

⁶Estimated. ⁷Revised.⁸Table includes data available through June 16, 1992.⁹In addition to the countries listed, Uganda may produce lead, but available information is inadequate to make reliable estimates of output levels.¹Reported figure.²Less than 1/2 unit.³Year beginning Mar. 21 of that stated.⁴Reported for 1987 and 1988 as galena (not further specified), assumed 78% Pb.⁵Pb content of ore milled in year beginning Apr. 1 of that stated.

TABLE 19
LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY¹

(Thousand metric tons)

Country	1987	1988	1989	1990	1991*
Argentina:					
Primary	'13.0	14.0	'14.0	'12.0	13.0
Secondary	'13.0	15.0	13.0	'11.0	11.0
Total	'26.0	29.0	'27.0	'23.0	24.0
Australia:					
Primary	201.7	168.0	193.0	212.0	'220.0
Secondary*	15.0	'17.0	'18.0	'20.0	20.0
Total*	216.7	'185.0	'211.0	'232.0	240.0
Austria:					
Primary	6.8	'8.3	'9.4	'9.0	6.4
Secondary	16.0	'16.7	'14.6	'15.2	16.3
Total	22.8	25.0	24.0	'24.2	22.7
Belgium:					
Primary	71.1	83.2	72.7	'70.8	70.0
Secondary	36.9	43.4	36.8	'32.2	30.0
Total ³	108.0	126.6	109.4	'103.0	100.0
Bolivia: Primary	.2	(⁴)	(⁴)	'1.2	1.2
Brazil:					
Primary	29.8	29.5	'32.5	'35.0	35.0
Secondary	58.4	68.7	53.3	55.0	55.0
Total	88.2	98.2	'85.8	'90.0	90.0
Bulgaria:⁵					
Primary	88.0	'83.0	89.0	'56.0	40.0
Secondary	17.0	17.0	10.0	10.0	10.0
Total	105.0	'100.0	'99.0	'66.0	50.0
Burma: Primary	4.0	4.4	3.4	'1.6	'2.8
Canada:					
Primary	139.5	'179.5	157.3	'102.7	100.0
Secondary	91.2	'89.9	'85.5	'92.3	91.0
Total ³	230.7	'269.4	'242.8	'195.0	191.0
China:⁶					
Primary	200.0	200.0	245.0	'240.0	265.0
Secondary	45.0	45.0	55.0	'56.0	65.0
Total	245.0	245.0	300.0	'296.0	330.0
Colombia: Secondary*	4.0	4.0	3.5	3.5	3.5
Czechoslovakia: Secondary	26.0	26.0	26.0	23.7	22.0
Finland: Secondary*	'(⁷)	'(⁷)	'(⁷)	'(⁷)	—
France:					
Primary	138.8	146.5	149.3	'162.3	160.0
Secondary	107.1	109.2	118.1	'108.2	100.0
Total	245.9	255.7	267.4	'270.5	260.0

See footnotes at end of table.

TABLE 19—Continued
LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY¹

(Thousand metric tons)

Country	1987	1988	1989	1990	1991*
Germany: Federal Republic of					
Primary:					
Eastern states*	² 21.6	¹ 13.8	¹ 14.0	¹ 15.8	—
Western States	167.6	176.6	¹ 170.7	¹ 162.0	172.0
Total primary	<u>189.2</u>	<u>190.4</u>	<u>184.7</u>	<u>177.8</u>	<u>172.0</u>
Secondary:					
Eastern states	⁴ 40.5	² 25.8	² 26.1	² 29.7	30.0
Western States	172.8	168.5	¹ 179.1	¹ 186.7	201.0
Total secondary	<u>213.3</u>	<u>194.3</u>	<u>205.2</u>	<u>216.4</u>	<u>231.0</u>
Total	<u>402.5</u>	<u>384.7</u>	<u>389.9</u>	<u>394.2</u>	<u>403.0</u>
Greece: Primary	¹ 7	¹ 13.1	⁵ 5.6	⁵ 5.2	5.0
Guatemala: Secondary	.1	.1	¹ .1	¹ .1	.1
Hungary: Secondary*	.1	.1	.1	.1	.1
India:					
Primary	20.7	18.8	21.3	² 29.9	33.1
Secondary	12.1	9.9	13.5	¹ 16.8	26.3
Total³	<u>32.8</u>	<u>28.7</u>	<u>34.7</u>	<u>46.7</u>	<u>59.4</u>
Iran: Secondary*	10.0	10.0	⁹ 9.0	10.0	10.0
Ireland: Secondary	9.6	11.7	¹ 12.0	¹ 12.0	12.0
Italy:					
Primary	62.3	72.2	74.2	¹ 73.0	72.0
Secondary	111.4	111.6	112.0	¹ 100.0	100.0
Total	<u>173.7</u>	<u>183.8</u>	<u>186.2</u>	<u>173.0</u>	<u>172.0</u>
Jamaica: Secondary*	1.0	1.0	1.0	1.0	1.0
Japan:					
Primary	218.8	217.7	207.7	204.9	² 220.1
Secondary	119.5	122.2	125.6	124.1	² 108.0
Total³	<u>338.3</u>	<u>340.0</u>	<u>333.4</u>	<u>329.0</u>	<u>328.1</u>
Kenya: Secondary*	2.0	2.0	1.0	1.0	1.0
Korea, North: Primary*	95.0	95.0	95.0	95.0	75.0
Korea, Republic of:					
Primary	52.5	46.0	36.8	38.0	40.0
Secondary	30.0	44.0	44.1	45.0	40.0
Total	<u>82.5</u>	<u>90.0</u>	<u>80.9</u>	<u>83.0</u>	<u>80.0</u>
Malaysia: Secondary	9.0	15.0	16.0	¹ 16.0	16.0
Mexico:					
Primary	¹ 173.8	¹ 168.0	¹ 160.0	¹ 167.0	160.0
Secondary*	³ 35.0	35.0	35.0	35.0	35.0
Total⁴	<u>208.8</u>	<u>203.0</u>	<u>195.0</u>	<u>202.0</u>	<u>195.0</u>
Morocco:					
Primary	62.5	68.4	63.7	⁶ 64.0	64.0
Secondary*	2.0	2.0	2.0	2.0	2.0
Total⁴	<u>64.5</u>	<u>70.4</u>	<u>65.7</u>	<u>66.0</u>	<u>66.0</u>
Namibia: Primary	40.6	44.4	44.2	³ 35.1	³ 33.4
Netherlands: Secondary	⁴ 40.3	³ 39.5	⁴ 41.5	⁴ 44.1	40.0
New Zealand: Secondary*	³ 3.6	3.0	5.0	5.0	5.0

See footnotes at end of table.

TABLE 19—Continued
LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY¹

(Thousand metric tons)

Country	1987	1988	1989	1990	1991*
Nigeria: Secondary*	20.3	0.5	0.5	0.3	0.5
Pakistan: Secondary*	2.0	2.0	2.0	2.0	2.0
Peru:					
Primary	71.3	56.5	73.4	*69.3	75.9
Secondary*	5.0	5.0	5.0	5.0	5.0
Total*	76.3	61.5	78.4	74.3	80.9
Philippines: Secondary*	7.0	7.0	7.0	7.0	7.0
Poland:					
Primary*	64.5	61.0	61.0	57.0	60.0
Secondary*	25.0	30.0	20.0	22.0	20.0
Total	89.5	91.0	81.0	*79.0	80.0
Portugal: Secondary*	6.5	6.5	6.5	5.0	5.0
Romania:*					
Primary	*28.0	*27.0	*24.0	*25.0	20.0
Secondary	10.0	10.0	15.0	10.0	9.0
Total	*38.0	*37.0	*39.0	*35.0	29.0
South Africa, Republic of: Secondary	38.3	37.4	36.9	*31.2	*32.1
Spain:					
Primary	71.4	*68.8	68.3	*60.0	65.0
Secondary	51.3	*52.0	*51.8	*45.0	50.0
Total	122.7	*120.8	*120.1	*105.0	115.0
Sweden:					
Primary	61.2	57.8	48.7	*47.5	50.0
Secondary	30.2	26.9	22.7	*22.1	24.0
Total	91.4	84.7	71.4	*69.6	74.0
Switzerland: Secondary	2.5	1.5	*1.5	*5.7	5.0
Taiwan: Secondary*	66.4	67.3	58.2	57.6	40.0
Thailand: Secondary	11.4	15.6	18.7	15.9	*12.9
Trinidad and Tobago: Secondary*	1.8	1.8	1.8	1.8	1.8
Tunisia:*					
Primary	2.2	2.2	2.2	2.2	2.2
Secondary	.5	.5	.5	.5	.5
Total	2.7	2.7	2.7	2.7	2.7
Turkey:*					
Primary	7.0	7.3	*4.6	8.4	6.1
Secondary	3.0	3.7	*2.4	3.6	3.1
Total	10.0	11.0	*7.0	12.0	9.2
U.S.S.R.:*					
Primary	475.0	447.0	465.0	420.0	380.0
Secondary	275.0	280.0	280.0	280.	250.0
Total	750.0	727.0	745.0	700.0	630.0

See footnotes at end of table.

TABLE 19—Continued
LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY¹

(Thousand metric tons)

Country	1987	1988	1989	1990	1991 ^a
United Kingdom:					
Primary	¹ 145.8	172.2	156.5	¹ 155.9	160.0
Secondary	² 201.1	201.6	193.5	¹ 173.5	175.0
Total	³ 346.9	³ 373.8	³ 350.0	³ 329.4	³ 335.0
United States:					
Primary	373.6	392.1	396.5	403.7	³ 345.7
Secondary	710.2	736.4	891.3	⁹ 922.2	⁸ 883.7
Total	1,083.8	1,128.5	1,287.8	¹ 1,325.9	² 1,229.4
Venezuela: Secondary ^a	17.0	18.0	17.0	17.0	17.0
Yugoslavia:					
Primary	76.4	70.9	⁹ 99.6	⁸ 82.0	70.0
Secondary	36.0	³ 39.0	¹ 18.0	¹ 17.0	18.0
Total	112.4	109.9	¹ 117.6	⁹ 99.0	88.0
Zambia: Primary ⁶	7.6	6.3	⁶ 6.0	⁶ 6.0	6.0
Grand total: ³	⁵ 5,721.9	⁵ 5,815.7	⁵ 5,971.8	⁵ 5,830.0	5,642.3
Of which:					
Primary	³ 3,192.9	³ 3,219.7	³ 3,264.6	³ 3,129.5	3,028.9
Secondary	² 2,529.1	² 2,596.1	² 2,707.2	² 2,700.6	2,613.4

^aEstimated. ^bRevised.

¹Table includes data available through June 16, 1992. Data included represent the total output of refined lead by each country, whether derived from ores and concentrates (primary) or scrap (secondary), and include the lead content of antimonial lead, but exclude, to the extent possible, simple remelting of scrap.

²Reported figure.

³Data may not add to totals shown because of independent rounding.

⁴Less than 50 tons.

⁵Revised to zero.

⁶Data are for fiscal year beginning Apr. 1 of that stated.

TABLE 20
PRODUCTION AND SHIPMENTS OF LEAD PIGMENTS¹ AND OXIDES IN THE UNITED STATES

(Metric tons unless otherwise specified)

Product	1990				1991			
	Production		Shipments		Production		Shipments	
	Gross weight	Lead content	Quantity	Value ²	Gross weight	Lead content	Quantity	Value ²
White lead, dry	W	W	W	W	W	W	W	W
Litharge and red lead	85,855	79,717	78,958	\$65,010,852	86,870	80,614	82,529	\$59,881,085
Lead oxide	⁴ 451,443	⁴ 428,871	NA	NA	439,218	417,257	NA	NA
Total ³	⁵ 537,298	⁵ 508,588	NA	NA	526,089	497,870	NA	NA

^aRevised. NA Not available. W Withheld to avoid disclosing company proprietary data.

¹Excludes basic lead sulfate; withheld to avoid disclosing company proprietary data.

²At plant, exclusive of container.

³Data may not add to totals shown because of independent rounding.

TABLE 21
U.S. IMPORTS FOR CONSUMPTION OF LEAD PIGMENTS AND
COMPOUNDS, BY KIND

Kind	Quantity (metric tons)	Value (thousands)
1990		
White lead carbonate	72	\$120
Red and orange lead	212	298
Chrome yellow and molybdenum orange pigments and lead-zinc chromates	4,983	11,075
Litharge	11,078	10,078
Leady litharge	183	182
Glass frits (undifferentiated)	6,552	11,358
Total¹	23,082	33,110
1991		
White lead carbonate	79	137
Red and orange lead	233	507
Chrome yellow and molybdenum orange pigments and lead-zinc chromates	4,614	10,519
Litharge	13,442	8,476
Leady litharge	437	348
Glass frits (undifferentiated)	5,141	9,981
Total¹	23,946	29,967

¹Revised.

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 22
U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Ore and concentrates (lead content):				
Australia	—	—	11,412	\$5,342
Bahamas	—	—	4	3
Belgium	17,346	\$9,492	44,411	10,595
Brazil	4,718	3,061	—	—
Canada	19,484	12,421	3,454	2,042
Haiti	—	—	29	16
India	9,511	4,931	—	—
Italy	1,867	1,685	—	—
Japan	2,898	1,015	11,943	2,714
Mexico	101	31	5,339	1,263
Spain	—	—	10,420	2,892
Taiwan	—	—	29	9
United Kingdom	632	713	603	187
Venezuela	—	—	310	96
Other	43	20	—	—
Total¹	56,600	33,369	87,953	25,159
Ash and residues (lead content):				
Belgium	11,656	6,895	6,807	2,511
Brazil	889	241	—	—
Canada	2	4	2	2
France	69	188	—	—
Germany, Federal Republic of	37	617	—	—
India	86	81	4,899	1,572
Mexico	—	—	91	8
United Kingdom	14	57	30	14
Other	11	14	—	—
Total¹	12,765	8,096	11,828	4,106
Unwrought lead and lead alloys (lead content):				
Australia	—	—	5	18
Belgium	28	69	—	—
Brazil	96	206	40	103
Canada	7,286	6,647	4,819	4,437
Chile	283	258	485	485
China	19	32	710	539
Dominican Republic	19	18	—	—
France	—	—	32	66
Germany, Federal Republic of	39	52	13	18
Haiti	69	109	56	27
Hong Kong	320	374	83	89
Indonesia	17	21	2,288	1,507
Israel	1,934	1,820	1,002	805

See footnotes at end of table.

TABLE 22—Continued
U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Unwrought lead and lead alloys (lead content)—Continued:				
Italy	3,004	\$3,354	16	\$26
Jamaica	—	—	31	19
Japan	4,049	5,648	8,270	7,556
Korea, Republic of	14,488	15,321	38,033	26,491
Malaysia	3,720	4,801	4,900	3,762
Malta	28	38	—	—
Mexico	145	191	569	691
Netherlands	2,826	2,366	101	149
Peru	23	47	—	—
Philippines	21	19	297	191
Saudia Arabia	—	—	17	14
Singapore	5,623	5,021	1,228	1,059
Sudan	313	263	—	—
Taiwan	11,553	11,229	27,737	19,304
Thailand	—	—	124	115
Trinidad and Tobago	17	18	—	—
United Kingdom	1,133	910	3,518	2,198
Venezuela	—	—	51	245
Other	172	250	3	68
Total¹	57,226	59,080	94,428	69,982
Wrought lead and lead alloys (lead content):				
Argentina	15	20	1	6
Australia	14	107	11	127
Bahamas	50	79	26	46
Barbados	1	9	14	18
Belgium	108	287	17	23
Brazil	57	148	5	10
British Virgin Islands	4	3	—	—
Canada	1,362	3,136	1,114	2,726
Chile	8	37	1,518	2,478
Colombia	30	75	—	—
Dominican Republic	24	45	(²)	7
Ecuador	4	8	3	4
Egypt	51	222	36	129
Finland	1	7	—	—
France	31	138	105	216
Germany, Federal Republic of	214	586	107	326
Guatemala	5	15	3	25
Haiti	24	89	122	496
Hong Kong	162	407	37	379
India	255	181	167	101
Israel	67	177	216	210
Italy	1,126	2,088	8	103
Jamaica	—	—	95	350

See footnotes at end of table.

TABLE 22—Continued
U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Wrought lead and lead alloys (lead content)—Continued:				
Japan	336	\$2,821	152	\$990
Korea, Republic of	319	781	316	1,093
Malta	(^o)	21	4	7
Mexico	1,527	5,301	1,853	6,855
Netherlands	112	352	82	308
Philippines	30	142	311	424
Saudia Arabia	48	216	44	110
Singapore	38	268	43	329
South Africa, Republic of	—	—	269	60
Spain	128	219	(^o)	6
Sweden	—	—	10	21
Taiwan	214	679	219	809
Thailand	38	306	32	210
United Kingdom	134	333	458	879
Venezuela	88	57	93	225
Other	131	563	125	507
Total¹	6,759	19,923	7,615	20,614
Grand total¹	133,349	120,468	201,824	119,860
Scrap (gross weight):				
Bahamas	127	129	7	29
Belgium	87	34	185	62
Brazil	2,512	1,111	4,457	959
Canada	34,497	11,190	54,488	10,105
China	3,507	1,472	3,286	2,522
France	640	221	274	83
Germany, Federal Republic of	4,551	1,629	1,011	278
Hong Kong	492	440	1,431	918
India	1,989	702	1,706	1,093
Indonesia	1,394	678	4,764	1,023
Ireland	198	131	186	128
Italy	511	61	47	104
Japan	1,135	1,347	1,386	1,275
Jordan	—	—	350	35
Korea, Republic of	2,301	2,324	2,267	1,108
Mexico	9,391	4,427	5,399	1,895
Netherlands	94	47	211	120
Netherlands Antilles	6	27	—	—
Panama	86	23	17	14
Philippines	44	190	3,525	660
Saudi Arabia	(^o)	3	—	—
Singapore	644	541	(^o)	10
South Africa, Republic of	1,536	1,235	274	77
Spain	858	1,962	2,583	481
Taiwan	3,369	1,808	2,290	1,397

See footnotes at end of table.

TABLE 22—Continued
U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Scrap (gross weight)—Continued:				
Thailand	220	\$119	993	\$459
Trinidad and Tobago	291	59	96	20
United Kingdom	4,804	1,717	1,773	729
Venezuela	81	45	75	23
Other	139	264	180	407
Total¹	75,507	33,934	93,262	26,574

¹Data may not add to totals shown because of independent rounding.

²Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 23
U.S. EXPORTS OF LEAD¹

Year	Blocks, pigs, anodes, etc.				Wrought lead and lead alloys				Scrap (gross weight)		Ash and residues	
	Unwrought ²		Unwrought alloys		All forms, including foil and wire		Powder and flakes		Quantity	Value	Quantity	Value
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	(metric tons)	(thou- sands)	(metric tons)	(thou- sands)
1989	23,787	\$25,909	4,725	\$4,182	5,053	\$12,874	312	\$1,239	59,909	\$26,165	9,960	\$5,612
1990	50,194	50,554	7,031	8,526	6,030	18,987	729	936	75,507	33,934	12,765	8,096
1991	71,994	52,235	22,433	17,747	6,975	20,068	641	546	93,262	26,574	11,828	4,106

¹Lead content, unless otherwise specified.

²Includes bullion.

Source: Bureau of the Census.

TABLE 24
U.S. IMPORTS¹ OF LEAD, BY COUNTRY

Country	1989		1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Ore and concentrates:²						
Australia	'1,910	'\$1,306	'2,178	'\$1,503	—	—
Bolivia	'36	12	'32	'18	27	\$11
Canada	'189,906	'62,387	'128,675	'74,510	99,551	NA
Colombia	—	—	—	—	419	92
Germany, Federal Republic of	—	—	—	—	254	101
Greece	—	—	—	—	2,053	452
Honduras	21	11	—	—	—	—
Italy	—	—	'234	'297	—	—
Mexico	'40	27	'945	'1,048	7,177	2,910
Peru	'12,888	'5,293	'12,089	'8,164	24,114	6,044
Switzerland	—	—	73	18	45	62
Other	—	—	—	—	(³)	9
Total⁴	'204,802	'69,037	'144,226	'85,559	133,639	'9,680
Base bullion:						
Canada	37	31	38	30	19	11
China	345	173	91	43	17	7
Mexico	5,400	4,334	2,584	1,563	364	252
Other	—	—	—	—	19	13
Total	5,782	4,538	2,713	1,636	419	283
Figs and bars:						
Australia	—	—	6,992	5,751	7,995	4,018
Belgium	41	25	—	—	21	12
Bolivia	52	48	—	—	—	—
Brazil	1,510	974	—	—	12	7
Canada	90,479	61,951	70,662	58,099	83,627	50,960
China	6	5	—	—	—	—
Germany, Federal Republic of	144	269	66	253	25	79
India	—	—	330	223	—	—
Italy	1,731	1,238	—	—	—	—
Mexico	19,178	13,232	24,666	19,988	23,410	13,139
Netherlands	—	—	5	5	—	—
Panama	—	—	—	—	79	29
Peru	4,316	2,913	1,000	822	500	228
Sweden	—	—	—	—	1,204	666
United Arab Emirates	296	510	239	646	113	342
United Kingdom	'277	'319	269	332	274	304
Venezuela	126	81	13	11	—	—
Yugoslavia	(⁵)	(⁵)	—	—	—	—
Other	—	—	—	—	11	16
Total⁴	'118,156	'81,565	'104,241	'86,129	117,270	'69,801

See footnotes at end of table.

TABLE 24—Continued
U.S. IMPORTS¹ OF LEAD, BY COUNTRY

Country	1989		1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Reclaimed scrap, including ash and residues:⁷						
Canada	487	\$182	233	\$119	197	\$51
Japan	(²)	4	—	—	—	—
Mexico	—	—	116	30	—	—
Netherlands Antilles	332	169	—	—	—	—
Total	819	355	349	149	197	51
Grand total	³329,559	⁴155,495	⁵251,529	⁶173,473	251,525	⁷79,815

¹Revised. NA Not available.

²Data are "general imports;" that is, they include lead imported for immediate consumption plus material entering the country under bond.

³Also includes other lead-bearing materials containing greater than 5 troy ounces of gold per short ton, or greater than 100 troy ounces of total precious metals per short ton.

⁴Less than 1/2 unit.

⁵Data may not add to totals shown because of independent rounding.

⁶Value data for Canada is not included in total.

⁷Revised to zero.

⁸Also includes other lead-bearing materials containing greater than 10% by weight of copper, lead, or zinc (any one).

Source: Bureau of the Census.

TABLE 25
U.S. IMPORTS FOR CONSUMPTION OF LEAD, BY COUNTRY

Country	1989		1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Ore and concentrates (lead content):¹						
Australia	—	—	'1,478	'\$534	—	—
Canada	'2,124	'\$830	'2,137	'515	4,961	\$1,384
Germany, Federal Republic of	—	—	—	—	254	101
Honduras	21	11	—	—	(^o)	9
Italy	—	—	'234	'297	—	—
Mexico	'40	'27	'968	'1,052	7,177	2,910
Peru	'2,937	'1,107	'5,778	'2,751	—	—
Switzerland	—	—	73	18	45	62
Total	'5,122	'1,975	'10,668	'5,167	12,437	4,466
Base bullion (lead content):						
Canada	37	31	38	30	19	11
China	345	173	91	43	17	7
Mexico	5,400	4,334	2,584	1,563	364	252
Other	—	—	—	—	19	13
Total	5,782	4,538	2,713	1,636	419	283
Figs and bars (lead content):						
Australia	—	—	—	—	7,995	4,018
Belgium	41	25	—	—	21	12
Bolivia	52	48	—	—	—	—
Brazil	1,510	974	—	—	12	7
Canada	90,479	61,951	70,662	58,099	83,627	50,960
China	6	5	—	—	—	—
Germany, Federal Republic of	144	269	66	253	25	79
India	—	—	330	223	—	—
Italy	1,731	1,238	—	—	—	—
Mexico	18,703	12,900	18,055	14,005	22,614	12,688
Panama	—	—	—	—	79	29
Peru	2,316	1,543	1,000	822	500	228
Sweden	—	—	—	—	1,204	666
United Arab Emirates	296	510	239	646	113	342
United Kingdom	277	319	269	332	274	304
Venezuela	126	81	13	11	—	—
Other	—	—	—	—	11	16
Total²	115,681	79,863	90,638	74,395	116,473	69,351
Reclaimed scrap, including ash and residues (lead content):⁴						
Canada	345	113	165	72	117	28
Japan	(^o)	4	—	—	—	—
Mexico	—	—	116	30	—	—
Netherlands Antilles	332	169	—	—	—	—
Total³	677	286	281	102	117	28
Grand total³	'127,262	'86,662	'104,300	'81,299	129,446	74,128

See footnotes at end of table.

TABLE 25—Continued
U.S. IMPORTS FOR CONSUMPTION OF LEAD, BY COUNTRY

Country	1989		1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Wrought lead, all forms, including wire and powders (gross weight):						
Belgium	68	\$181	1	\$86	1	\$17
Canada	770	1,257	1,152	2,068	1,166	1,839
China	279	719	278	771	136	367
France	—	—	21	140	111	370
Germany, Federal Republic of	244	837	258	1,167	210	836
Italy	50	160	330	448	817	982
Japan	37	393	37	399	46	539
Mexico	2,539	1,797	2,769	2,061	2,628	1,556
Netherlands	—	—	55	241	46	131
Peru	1,284	927	735	628	133	100
Spain	7	117	4	96	—	—
Taiwan	248	658	178	495	160	469
Thailand	—	—	30	120	(?)	2
United Arab Emirates	—	—	40	101	60	128
United Kingdom	406	989	88	513	144	548
Venezuela	—	—	709	366	26	16
Other	136	1,041	40	245	108	561
Total ³	6,068	9,076	6,723	9,944	5,792	8,460

¹Revised.

²Also includes other lead-bearing materials containing greater than 5 troy ounces of gold per short ton, or greater than 100 troy ounces of total precious metals per short ton.

³Less than 1/2 unit.

⁴Data may not add to totals shown because of independent rounding.

⁵Also includes other lead-bearing materials containing greater than 10% by weight of copper, lead, or zinc (any one).

Source: Bureau of the Census.

TABLE 26
U.S. IMPORTS FOR CONSUMPTION OF LEAD¹

Year	Blocks, pigs, anodes, etc.				Wrought lead and lead alloys (gross weight)						Scrap		Ash and residues	
	Unwrought ²		Unwrought alloys		Strip, sheets, plates, and foil		Bars, rods, tubes, pipe, wire, fittings		Powders and flakes		Quan- tity (metric tons)	Value (thou- sands)	Quan- tity (metric tons)	Value (thou- sands)
	Quan- tity (metric tons)	Value (thou- sands)	Quan- tity (metric tons)	Value (thou- sands)	Quan- tity (metric tons)	Value (thou- sands)	Quan- tity (metric tons)	Value (thou- sands)	Quan- tity (metric tons)	Value (thou- sands)				
1989	102,319	\$71,823	19,144	\$12,578	718	\$1,356	5,337	\$7,670	13	\$50	—	—	677	\$286
1990	81,490	65,059	11,861	10,972	427	1,126	6,197	8,634	98	185	—	—	281	102
1991	102,745	59,730	14,147	9,905	486	818	4,524	6,856	782	786	—	—	117	28

¹Lead content, unless otherwise specified.

²Includes bullion.

Source: Bureau of the Census.

TABLE 27
U.S. IMPORTS FOR
CONSUMPTION OF
MISCELLANEOUS PRODUCTS
CONTAINING LEAD¹

Year	Gross weight (metric tons)	Lead content (metric tons)	Value (thousands)
1988	1,623	992	\$8,838
1989 ²	1,789	852	11,908
1990	1,238	515	6,782
1991	2,818	1,154	4,133

¹Babbitt metal, solder, white metal, and other lead-containing combinations.

²Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989, 1990, and 1991 are not necessarily comparable with those in previous years.

Source: Bureau of the Census.

LIME

By M. Michael Miller

Mr. Miller, a physical scientist with 14 years of minerals experience with the Department of the Interior, has been the commodity specialist for lime since 1989. Domestic survey data were prepared by Blanche S. Hughes, statistical assistant; and the world production table was prepared by Harold D. Willis, international data assistant.

Lime is an important chemical with hundreds of chemical, industrial, and environmental uses in the United States. It is a basic chemical that ranked sixth in total production in the United States in 1991. Its major uses are in steelmaking; pulp and paper manufacturing; construction; and the treatment of water, sewage, and smokestack emissions.

Total lime sold or used by domestic producers, including that from Puerto Rico, decreased by about 178,000 short tons to 17.3 million short tons in 1991. Production included the commercial sale or captive consumption of quicklime, hydrated lime, and dead-burned refractory dolomite. These products were valued at more than \$895 million. Commercial sales decreased for the first time in 5 years, while captive consumption remained essentially unchanged from 1990 levels.

DOMESTIC DATA COVERAGE

Domestic production data for lime are developed by the U.S. Bureau of Mines from two separate, voluntary surveys of U.S. operations. The survey used to prepare this report is the annual "Lime" survey. Of the 116 operations to which the annual survey request was sent, 101 responded, representing 85% of the total sold or used by producers shown in table 4. Production for seven nonrespondents was provided based on the monthly survey. Production for five nonrespondents was estimated using reported prior-year production figures. There were three plants idle or shut down. (See table 1.)

BACKGROUND

Definitions and Specifications¹

Lime is a manufactured product made by calcining limestone (calcium carbonate or a combination of calcium and magnesium carbonate) or other calcium carbonate materials at temperatures ranging from 1,800° F to 2,400° F. It is never found in a natural state. The calcination process drives off the carbon dioxide, forming calcium oxide (quicklime). The subsequent addition of water creates calcium hydroxide (hydrated or slaked lime). The term "lime" is a general term that includes the various chemical and physical forms of quicklime and hydrated lime. It may be high calcium, magnesian, or dolomitic. Quicklime is calcium oxide (CaO) with no water of crystallization. Hydrate is hydrated calcium oxide, or calcium hydroxide [Ca(OH)₂], and contains 24% combined water. Dead-burned refractory dolomite is dolomite that has been calcined at 2,800° F to 3,150° F. All of these products are called lime.

Quicklime is commercially available by the carload, in bulk, or in paper bags, in the following standard sizes:

1. Lump lime—the product exceeds 2.5 inches in diameter. Although sizes can vary, the typical size is 5 by 8 inches. This largest size of quicklime is strictly a product of vertical kilns.

2. Crushed or pebble lime—the product ranges in size from 0.25 inch to 2.25 inches, but the specific product size is more precise. This size has traditionally been a product of rotary kilns, but is now available from vertical kilns as either a

primary product or as a result of crushing lump lime.

3. Ground lime—the product is generally ground from larger size material. A typical product size passes nearly 100% through a No. 8 sieve and 40% to 60% through a No. 100 sieve.

4. Pulverized lime—the product is the result of further grinding. A typical product size passes nearly 100% through a No. 20 sieve and 85% to 95% through a No. 100 sieve. This is usually a secondary product and is produced by intense grinding and classification.

5. Pelletized lime—the almond-shaped pellets or briquets are of uniform 1-inch size, molded from quicklime fines.

Hydrated lime is shipped in bulk tank trucks, rail cars, and in 50-pound paper bags. As a result of the hydration process, it is of fine particle size. A typical product size passes 85% or more through a No. 200 sieve, and a few special applications may require a product passing 95% to 98% through a No. 325 sieve.

Because of the differences in limestones, a rigid standardization of lime material specifications is impossible. Few plants manufacture lime with exactly the same properties; as a result, lime specifications are by necessity quite general in their provisions. (See table 2.)

Technology²

Lime manufacture involves three main processes: stone preparation, calcination, and hydration. Stone preparation involves quarrying or mining (including drilling, blasting, and conveying broken stone), crushing, and screening to provide the proper size kiln feed. Care is taken

to avoid contamination with undesirable impurities, such as iron oxide, silica, and alumina. Although most lime manufacturers produce their own stone, some purchase the stone for kiln feed from commercial limestone producers.

Calcination is a simple chemical reaction. It is the addition of heat to limestone to cause thermal decomposition, in which the coproducts of CaO (quicklime) and CO₂ (carbon dioxide) are formed. This process is performed in a kiln, of which there are a wide variety of systems in use. The two basic kiln designs are rotary and vertical (or shaft). There are a few other miscellaneous designs, but the majority of commercial kilns are of rotary or vertical design.

A rotary kiln is a long cylindrical kiln with a refractory lining, inclined at a slight angle, rotated at a slow speed, and fired by fuel at the lower end. The calcareous raw material (kiln feed) is fed into the upper end and calcined at about 2,000° F during its travel through the kiln to form quicklime, which is discharged at the lower end. The calcination temperature depends on size and composition of kiln feed and the type of desired product. The carbon dioxide is driven off as a gas and normally exits the system with the stack gas.

Vertical kilns are short, wide, vertical cylinders lined with refractory materials. They are usually circular in cross section, typically with a diameter of 9 to 14 feet and a height of 50 to 70 feet. They are the most widely employed type in the world, especially in Europe. A vertical kiln is divided into four distinct zones where specific parts of the manufacturing process take place. They are, from top to bottom, (1) stone storage zone, (2) preheating zone, (3) calcining zone, and (4) cooling and discharge zone.

Examples of other kiln designs are the rotary hearth kiln and the fluosolids kiln. The rotary hearth design consists of a preheater, circular hearth, and cooler, all refractory lined. Stone is placed on the hearth and rotated through a heating chamber. In the fluosolids kiln, fine-sized stone is densely suspended by air and hot gases in the preheating and

calcining zone of a vertical heated chamber. It can be operated at lower temperatures because of the fine stone size. The quicklime product is the most highly reactive of any commercial lime.

Byproducts and Coproducts

Most lime companies mine their own limestone or dolomite for kiln feed. Some companies also produce a separate coproduct crushed and pulverized stone production. If practical and if markets exist, byproduct fines from the kiln feed preparation process and kiln dust from the calcination process are also marketed. Precipitated calcium carbonate (PCC) is produced as a coproduct at three commercial lime plants by combining quicklime with byproduct carbon dioxide recovered from the kiln. Byproduct carbon dioxide is also recovered for use in the carbonation step of sugar refining.

Substitutes

Limestone is a low-cost substitute for lime for many uses such as agriculture, fluxing, and flue gas desulfurization (FGD). Limestone contains less reactive material, is slower to react, and may have other disadvantages compared to lime, depending on the use. Calcined gypsum is an alternative material in industrial plasters and mortars. Cement, lime kiln dust, and fly ash are potential resources as substitutes for some construction uses of lime. Alkalis such as caustic soda, soda ash, sodium bicarbonate, sodium sulfate, and magnesium hydroxide are substitutes used in the neutralization stage of water treatment.

Economic Factors

Prices.—Traditionally, lime has been a low-priced commodity. Its average value, as reported to the U.S. Bureau of Mines on an f.o.b. plant basis, ranged from \$4 to \$15 per ton from 1910 to 1970. It was only in the 1970's, when energy prices escalated, that lime prices showed a progressive and dramatic increase. This steady increase continued into the 1980's, although at a slower

pace. In 1987, lime decreased in value for the first time since 1968. When comparing prices over the past 20 years, based on constant 1991 dollars, two trends become evident. From 1972 to 1978, prices fluctuated, but finished the period up 41%. From 1979 to 1991, prices decreased steadily, finishing the period down almost 30%. (See table 3.)

Costs.—Production costs in lime manufacture can be divided, in descending order, into the following categories: energy (mainly fuel costs), kiln feed, dust collection, depreciation, direct labor, and miscellaneous. The ranking may differ from plant to plant, and most of the categories display a great range in costs from one plant to another. The difference in ranking and the range in costs are accounted for by such variables as distance from fuel sources; thermal efficiency of individual kilns; whether kiln feed is quarried, mined underground, or purchased; electrical energy rates; and age of the plant.³

Tariffs.—In the Harmonized Tariff Schedule of the United States, quicklime, slaked lime (hydrate), and hydraulic lime are listed under 2522.10, 2522.20, and 2522.30, respectively. Imports are free from countries with most-favored-nation (MFN) status and Canada. Non-MFN countries have tariffs of 0.2¢ per kilogram (about \$2.20 per short ton) for quicklime, 0.3¢ per kilogram (about \$3.31 per short ton) for slaked lime, and 0.2¢ per kilogram (about \$2.20 per short ton) for hydraulic lime. Mexican imports of lime are assessed a countervailing duty of 1.21%. This applies only to Mexican lime producers included in the scope of a countervailing duty investigation completed in 1984 and a changed circumstances administrative review completed in 1989.

ANNUAL REVIEW

Legislation and Government Programs

Title IV of the Clean Air Act Amendments of 1990 authorized the U.S.

Environmental Protection Agency (EPA) to establish an acid rain program to reduce the adverse effects of acidic deposition. As part of the implementation of this statutory mandate, four proposed rulemakings were issued on December 3, 1991. The proposed rules included: the permits regulation, the allowance system regulation, the continuous emissions monitoring regulation, and the excess emissions penalties regulation. These rulemakings regulate the four core components of the acid rain program: the permit, which includes a source's emissions control plans and requirements; the allowance system, which provides a source the flexibility to meet its sulfur dioxide emissions limitation requirements economically; the continuous emissions monitoring system, which ensures source compliance; and the excess emissions program, which defines the consequences for failing to comply with the sulfur dioxide and nitrogen oxides emissions requirements.⁴

Production

The term "lime," as used throughout this chapter, refers primarily to six chemicals produced by the calcination of high-purity calcitic or dolomitic limestone followed by hydration where necessary. They are (1) quicklime, calcium oxide (CaO); (2) hydrated lime, calcium hydroxide [Ca(OH)₂]; (3) dolomitic quicklime (CaO•MgO); two types of dolomitic hydrate, (4) type N [Ca(OH)₂•MgO] and (5) type S [Ca(OH)₂•Mg(OH)₂]; and (6) dead-burned dolomite. Nondolomitic quicklime and hydrated lime are also called high-calcium lime. Lime can also be produced from a variety of calcareous materials such as aragonite, chalk, coral, marble, and shell. Lime is also regenerated; that is, produced as a byproduct, by paper mills, carbide plants, and water treatment plants; however, regenerated lime is beyond the scope of this report.

Total U.S. lime production from limestone, including that of Puerto Rico, was essentially unchanged. Commercial

lime sold by producers decreased by 178,000 tons from that of the previous year. Captive lime used by producers remained essentially unchanged.

In 1991, 70 companies produced lime. Leading producing companies, in descending order, were Dravo Lime Co., with two plants in Kentucky and one plant in Alabama; Mississippi Lime Co. in Missouri; Marblehead Lime Co., with two plants in Illinois and one each in Indiana and Michigan; Chemstar Inc., with two plants each in Arizona, California, and Nevada and one in Utah; Allied Lime Co., with two plants in Alabama; Continental Lime Inc., with one plant each in Montana, Nevada, Utah, and Washington; Martin Marietta Corp. in Ohio; Chemical Lime Inc., with two plants in Texas; APG Lime Co., with one plant each in Texas and Virginia; and Wimpey Minerals PA Inc., with two plants in Pennsylvania. These 10 companies operated 28 plants and accounted for 57% of total lime production.

Domestic lime plant capacity is based on 365 days minus the average number of days for maintenance times the average 24-hour capacity of quicklime production, including quicklime converted to hydrated lime, and reported in short tons per year. Specific plant capacity data were available for 50 commercial lime plants. Based on the data available, the commercial lime industry operated at 74% of capacity in 1991. (See tables 4 and 5.)

The industry completed a number of plant expansions and started construction of a new plant. Dravo Lime Co. completed installation of an 800-ton-per-day preheater rotary kiln of Kennedy Van Saun design at its plant in Saginaw, AL. It went on-line in late March 1991. It replaced a 200-ton-per-day rotary, which was placed in inactive status. Dravo Lime Co. and Tenn Lutrell Co. announced a joint-venture agreement to market Dravo's patented Thiosorbic lime (magnesium enhanced lime) for FGD in Tennessee and the mid-Atlantic region. Tenn Lutrell will produce Thiosorbic lime at its lime plant near Knoxville, TN. Thiosorbic lime is the registered trademark of Dravo's magnesium-

enhanced lime. Cheney Lime and Cement Co. completed installation of a preheater rotary kiln of Kennedy Van Saun design at its plant near Alabaster, AL. It went on-line in the first quarter of 1991. Continental Lime Inc. completed installation of a second kiln at its plant at Townsend, MT. The kiln was a used Allis Chalmers with a preheater of Continental design and went on-line January 1991. The company began installation of a third rotary kiln at its plant at Delta, UT. The kiln was a used F. L. Smidth with a preheater of Continental design and is scheduled to go on-line in September 1992. Chemstar Inc. began construction of a 600-ton-per-day Maerz vertical shaft kiln at its Ten-Mile Plant near Soda Springs, ID. Startup was planned for early August 1992. Work on zoning and permitting approvals continued for a new plant planned for Cosgrave, NV. Construction is expected to begin in the third quarter of 1992. (See table 6.)

Consumption and Uses

Lime was consumed in every State. The breakdown of consumption by major end uses was as follows: 66% for chemical and industrial uses, 24% for environmental uses, 8% for construction uses, and 2% for refractory dolomite. Captive lime was used mainly in sugar refining and in the production of steel in basic oxygen furnaces.

In steel refining, quicklime was used as a flux to remove impurities such as phosphorus, silica, and sulfur. Dolomitic lime was often substituted for a fraction of the high-calcium lime to extend refractory life. Dead-burned dolomite, also called refractory lime, was used to line the bottom of open-hearth steel furnaces to extend the life of the brick lining until the last open-hearth furnaces operated by the U.S. steel industry closed down in 1991. Dead-burned dolomite was a component in tar-bonded refractory brick used in basic oxygen furnaces. Lime consumption for raw steel production remained essentially unchanged at 5.1 million tons and

accounted for about 30% of all lime consumed in the United States.

In nonferrous metallurgy, lime was used in the beneficiation of copper ores to neutralize the acidic effects of pyrite and other iron sulfides and maintain the proper pH in the flotation process. It was used to process alumina and magnesia, to extract uranium from gold slimes, and in the recovery of nickel by precipitation. It was used in gold and silver recovery operations to control the pH of the sodium cyanide solution used to leach the gold and silver from the ore. Such leaching processes are called dump leaching when large pieces of ore are involved, heap leaching when small pieces of ore are involved, and carbon-in-pulp cyanidation when the ore is leached in agitated tanks. Dump and heap leaching involve crushing the ore, mixing it with lime for pH control and agglomeration, and stacking the ore in heaps for treatment with cyanide solution. Lime is used to maintain the pH of the cyanide solution at a pH level between 10 and 11 to maximize precious-metals recovery and to prevent the creation of dangerous hydrogen cyanide gas.

In the environmental sector, lime was used in the softening and clarification of municipal potable water. In sewage treatment, lime was used to control pH in the sludge digester, which removes dissolved and suspended solids that contain phosphates and nitrogen compounds. It also aided clarification and killing of bacteria. Lime was used to neutralize acid mine and industrial discharges. In FGD systems serving utility and industrial plants, lime was used to react with sulfur oxides in the flue gas. Lime was used to stabilize sludges from sewage and desulfurization plants before disposal.

The paper industry used lime as a coagulant aid in the clarification of plant process water. It was used, generally in conjunction with soda ash, for softening plant process water. This is a precipitation process to remove bivalent soluble calcium and magnesium cations (and to a lesser extent manganese, ferrous iron, zinc, and strontium), which contribute to the hardness of water. This

process also reduces carbonate alkalinity and dissolved solids content.

In the basic Kraft pulping process, wood chips and an aqueous solution (called liquor) of sodium hydroxide and sodium sulfide are heated in a digester. The cooked wood chips (pulp) are discharged under pressure along with the spent liquor. The pulp is screened, washed, and sent directly to the paper machine or for bleaching. Lime is sometimes used to produce calcium hypochlorite bleach for bleaching the paper pulp. The spent liquor is processed through a recovery furnace where dissolved organics are burned to recover waste heat and where sodium sulfide and sodium carbonate are recovered. The recovered sodium sulfide and sodium carbonate are diluted with water and then treated with slaked lime to recausticize the sodium carbonate into sodium hydroxide (caustic soda) for reuse.

Lime was used to make PCC, a specialty pigment used in premium-quality coated and uncoated papers. The most common PCC production process used in the United States is the carbonation process. Carbon dioxide is bubbled through milk-of-lime to form a precipitate of calcium carbonate and water. The reaction conditions determine the size and shape of the resulting PCC crystals.

The chemical industry used lime in the manufacture of alkalis. Quicklime was combined with coke to produce calcium carbide, which was used to make acetylene and calcium cyanide. Lime was used to make calcium hypochlorite, citric acid, petrochemicals, and other chemicals.

In sugar refining, milk of lime, a suspension of hydrated lime in water, was used to raise the pH of the product stream, precipitating colloidal impurities. The lime itself was then removed by reaction with carbon dioxide to precipitate calcium carbonate. The carbon dioxide was obtained as a byproduct of lime production.

Dolomitic quicklime was used as a flux in the manufacture of glass. Quicklime was used to make calcium silicate building products such as sand-lime brick;

hydrated lime was used to produce silica refractory brick.

In construction, lime was used for soil stabilization to upgrade clay soils into satisfactory base and subbase materials. Common applications included the construction of roads, airfields, building foundations, earthen dams, and parking areas. Hydrated lime was used with fly ash to make a base material, in asphalt mixes to act as an antistripping agent, and in plaster, stucco, and mortar to improve durability. Other applications of lime included agricultural uses, leather tanning, plastics manufacture, and pigments. (See figure 1 and table 7.)

Prices

The average value of lime sold or used by producers, as reported to the U.S. Bureau of Mines on an f.o.b. plant basis, was essentially unchanged from that of the previous year at \$51.73 per short ton. Average values were \$49.80 per ton for chemical and industrial lime, \$61.80 for construction lime, \$71.16 for lime used in agriculture, and \$75.86 for refractory dolomite.

The average value of quicklime sold decreased to \$49.93 per ton. Average values per ton were \$48.27 for chemical lime, \$42.07 for construction lime, \$59.53 for lime used in agriculture, and \$74.17 for refractory dead-burned dolomite.

The average value of hydrated lime sold increased to \$63.30 per ton. Average values were \$60.69 for chemical lime, \$68.39 for lime used in construction, and \$76.95 for lime used in agriculture.

Foreign Trade

According to the Bureau of the Census, exports of lime decreased by 5% to 42,000 tons. Imports of lime remained essentially unchanged at 174,000 tons. Most U.S. trade was with Canada and Mexico, which together accounted for more than 99% of the U.S. imports and exports of lime. Canada was the major trading partner, receiving 90% of U.S.

exports and shipping 85% of U.S. imports. (See tables 8 and 9.)

World Review

Canada.—Shipments of lime were essentially unchanged from 1990 levels, but shipments in both 1990 and 1991 were 8% lower than those in 1989. In 1990, shipments were down owing to a 3-month strike in the steel industry. In 1991, shipments were down owing to the economic recession. Preliminary figures for 1991 indicate that Canada producers shipped about 2.12 million tons valued at \$186 million.

Germany, Federal Republic of.—German Group Preussag AG purchased Harz Kalk GmbH of Saxony-Anhalt. Harz Kalk GmbH was the largest producer of lime and limestone in the former German Democratic Republic. It operated six limestone and lime facilities: Werk Rbeland, Werk Kaltes Tal, Werk Hornberg, Werk Bad Ksen, Werk Oberrohn, and Werk Schraplau. Preussag AG, which has interests in energy, ship building, steel and nonferrous metal production, and trading, plans to invest about \$120 million to construct new lime production facilities and mortar plants. Harz Kalk will be operated as an independent group member company as a subsidiary of Fels-Werke GmbH.⁵

United Kingdom.—ICI announced the sale of its lime business to Luxembourg-based Minorco. ICI's lime business is in Derbyshire near Buxton and includes three quarries and two processing and calcining facilities. The largest lime plant is at Tunstead, with the capacity to produce 695,000 tons of quicklime per year and 330,000 tons of hydrate. The second plant is at Hindlow, with the capacity to produce 240,000 tons of quicklime per year. The company's major markets are steel, chemicals, sugar processing, and water treatment. The company is to be renamed Buxton Lime Industries.⁶

Tilcon Ltd., a subsidiary of BTR PLC, formed a 50-50 joint-venture company with Belgian lime and industrial minerals producer Calcitherm-Carmeuse Group. The new company, called Tilcon Carmeuse Ltd., will produce and market quicklime and hydrated lime in the United Kingdom. Feasibility and marketing studies were undertaken in 1991 to decide the number and location of new lime plants to be built at Tilcon's existing quarries. New plant construction is expected to be complete by mid-1993. The new plants will supply Tilcon's traditional markets: steel, construction, chemicals, water treatment, and sewage treatment.⁷

The 1st International Seminar on Lime and Other Alternative Cements was held on December 9-11, 1991, at Stoneleigh, Warwickshire, United Kingdom. About 60 participants attended from Europe, the United States, and other parts of the world. The seminar addressed the production of lime and lime pozzolana cements and their uses and applications. (See table 10.)

Current Research

The EPA at Research Triangle Park, NC, has conducted research into the use of hydrated lime to destroy dioxins in the vapor phase at medium temperatures (350° C). The results suggest that the reaction technology may be transferable to polychlorinated biphenyl (PCB's) vapor destruction and to chlorinated hydrocarbons such as pesticides. At present, destruction of these materials can only be accomplished at high temperatures (2,500° C). If the research proves out and the process can be scaled up, it could result in substantial cost savings over the high-temperature process.⁸

The Argonne National Laboratory, Department of Energy (DOE), has been test burning pelletized refuse-derived fuel that utilizes hydrated lime as a binder. Three test burns are currently funded, and DOE has tentatively accepted a proposal for a 5-year commercial development program. The new test program would examine the long-term

effects on boilers and boiler tube corrosion, mass-burn garbage plant retrofits, 100% refuse-derived fuel burns, and dolomitic lime use. Utilizing hydrated lime as a binder solves a problem that has vexed refuse-fuel researchers. Fuel pellets frequently broke up during transport and tended to fall apart during prolonged storage. Positive results of this program could create a new market for lime.⁹

Research was conducted to study combining industrial wastes with lime for soil stabilization. Experiments utilizing scanning electron microscope observations and X-ray diffraction analysis investigated chemical compounds of an anhydrous stabilizer and reaction products produced in hydrated stabilizer and stabilized soil. Results of the laboratory research were compared to the effectiveness of ordinary portland cement. The results indicated that a new stabilizer produced from the combination of lime and incinerated industrial wastes had self-cementing characteristics similar to portland cement. It would be suitable for addition to high-moisture loam soil and organic matter for subgrade stabilization purposes.¹⁰

Chemists, in the Department of Chemistry, University of Hannover, Federal Republic of Germany, have conducted research on the treatment of soil contaminated with PCB's using hydrophobic (water repellent) lime and other reagents. Their tests involved the in situ treatment of PCB-contaminated soil using a Dispersion by Chemical Reaction Process. This process uses quicklime treated with fatty acids as the carrier and dispersing agent for the additional reagents needed for the solid-phase treatment and dehalogenation of the PCB's. The specially prepared lime, when mixed with PCB-contaminated soil, preferentially absorbs the PCB's. The quicklime then undergoes a delayed exothermic reaction forming hydrated lime, which is broken into submicron-sized particles. These particles contain the dehalogenation reagents and absorb the PCB's. The hydrated lime slowly reacts with natural carbon dioxide to generate insoluble calcium carbonate.

This immobilizes the PCB's and provides an environment where the chemical reactivity of the compounds is increased, allowing detoxification and dehalogenation reactions to occur. The time required for these reactions to occur depends to a large extent on the temperature at which the process is run. Thus, the remediation process can be run in situ, where reaction times could take several months, or externally at elevated temperatures of about 400° C, where the reactions would take a matter of minutes.

Neither quicklime nor hydrated lime alone appears to be a successful treatment of PCB's. The key to the Dispersion by Chemical Reaction Process is the proprietary dehalogenation reagents. Using the described process and the reagents, the researchers achieved a dehalogenation reduction rate of 70% over a period of 7 days at ambient conditions.¹¹

OUTLOOK

Lime has dozens of end uses in the chemical, industrial, and construction industries. Steelmaking is still the largest single end use for lime, and although raw steel production in the United States decreased by 13% in 1991, the steel industry's consumption of lime remained essentially unchanged from 1990 levels. Consumption by the steel industry has been flat over the past 3 years. Steel output is expected to increase modestly in the short term, but should receive a boost from the passage of the Intermodal Surface Transportation Efficiency Act (ISTEA), which includes \$121 billion for highways and \$31.5 billion for transit. This should maintain this traditional lime market near or slightly above current consumption levels.

Other sectors of the lime market are more difficult to analyze. No other single end use consumes more than 10% of total consumption, although environmental uses when grouped together account for 24%. FGD consumption has the greatest growth potential, having increased steadily since the U.S. Bureau of Mines began collecting consumption data for it in the

early 1970's. With passage of the Clean Air Act Amendments of 1990, consumption of lime for FGD use is expected to show continued growth during the 1990's, although it appears that the FGD market may not grow as dramatically as originally anticipated. The majority of utility powerplants intending to install FGD scrubbers are leaning toward the use of limestone scrubbers instead of lime scrubbers. In addition, now that the desulfurization market has been recognized as a major market, more companies and Federal research laboratories have become involved in researching alternative desulfurization technologies.

Other environmental markets should be solid, with the greatest potential for growth in sewage sludge stabilization. Research continues into the use of lime combined with other reagents for the destruction of PCB's and dioxins. This potential coupled with its ability to neutralize acid wastes and to precipitate and immobilize heavy metals may lead to wider usage in environmental markets.

In the short term, major construction projects such as construction of the Denver International Airport will boost consumption of lime for soil stabilization. From 1993 through 1997, the highways allotment in ISTEA should provide a boost to the asphalt antistripping and soil stabilization markets. ISTEA has allotted in excess of \$20 billion per year for highway construction projects during that period.

Consumption by the pulp and paper industry was flat in 1990. According to experts in the chlor-alkali industry, consumption of caustic soda for pulp and paper is slowing and is expected to grow by 1% or less over the next 5 years. Because lime is used to recausticize sodium carbonate into caustic soda, consumption of lime by the pulp and paper industry is also expected to be flat. Lime consumption for PCC production will continue to increase as the push to build satellite PCC plants near paper mills continues.

Consumption of raw materials for glass manufacture is expected to grow at a rate of 1% per year through the mid-1990's.

Lime and limestone compete in the glass market with the choice depending on established manufacturing practice, regional availability, and prices. Lime consumption for glass manufacture is expected to outgrow limestone consumption owing to the lime's lower energy costs to the user.

Regionally, the continued expansion of gold production will provide a growing market in the West for lime consumed in cyanide-based gold recovery processes. Two producers of soda ash in Wyoming have constructed facilities for the lime-soda production of caustic soda, and a third is in the construction stage. This could develop into a significant regional market for lime.

In the south-central United States, a major regional market could develop in the middle to late 1990's. A major manufacturer of propylene oxide is considering switching from the use of caustic soda to hydrated lime for the dehydrochlorination stage of the manufacturing process. If the manufacturer proceeds with the substitution, the company would consume about 500,000 tons of hydrated lime per year.

A number of promising markets that are in the research or demonstration stage are lime used as a binder in refuse-derived fuel, PCB and dioxin treatment, and autoclaved cellular concrete. The latter is a construction material manufactured by mixing portland cement, lime, aluminum powder, water, and a large proportion (up to 75%) of sand or fly ash. The material has outstanding dimensional stability, is thermally efficient, fire resistant, easily worked, and is cost effective in terms of construction time and energy use. It has been in wide use in Europe for 25 years. An 18-month demonstration tour is scheduled in the United States for mid-1992.

¹National Lime Association. Chemical Lime Facts. Bull. 214, 5th ed., 1988, 44 pp.

²Boynston, R. S. Chemistry and Technology of Lime and Limestone. John Wiley & Sons, 1980, 578 pp.

³Pages 316-319 of work cited in footnote 2.

⁴U.S. Congress. Clean Air Act Amendments of 1990. Public Law 101-549, Nov. 15, 1990, 104 Stat. 2399.

⁵Industrial Minerals (London). Preussag Acquires Harz Kalk. No. 283, Apr. 1991, p. 12.

⁶_____. Minorco Buys ICI Lime Business. No. 292, Jan. 1992, p. 12.

⁷_____. Ticon Carmeuse Lime Jv. No. 287, Aug. 1991, p. 11.

⁸National Lime Association. Research Shows Dioxin Destruction by Hydrated Lime. Lime-Lites, v. LVIII, Jan.-June 1992, p. 34.

⁹_____. Refuse Derived Fuel. Lime-Lites, v. LVIII, Jan.-June 1992, p. 34.

¹⁰Karnon, M., and S. Nontananandh. Combining Industrial Wastes With Lime for Soil Stabilization. J. of Geotech. Eng., v. 117, No. 1, Jan. 1991, pp. 1-17; Highway Research Abstr. v. 24, No. 1, Spring 1991.

¹¹Payne, J., F. Boelsing, A. Habekost, G. Hirschfeld, and V. Birke. Complete Ambient-Temperature Dehalogenation of PCB's in Contaminated Soil Using Hydrophobic Lime and Other Reagents. Pres. at 1991 PCB Conference, Baltimore, MD, Oct. 8-11, 1991, 7 pp.; available from J. R. Payne, Sound Environmental Services, Inc., Sacramento, CA.

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Other Sources

Chemical Marketing Reporter.

Industrial Minerals (London).

Industrial Minerals and Rocks.

Lime Lites (quarterly newsletter of National Lime Association).

Pit and Quarry.

Rock Products.

TABLE 1
SALIENT LIME STATISTICS

(Thousand short tons unless otherwise specified)

	1987	1988	1989	1990	1991
United States:¹					
Number of plants	116	115	115	113	112
Sold or used by producers:					
Quicklime	12,979	14,066	14,500	14,762	14,541
Hydrated lime	2,468	2,531	2,249	2,313	2,390
Dead-burned dolomite	285	455	402	377	339
Total ²	15,557	17,052	17,152	17,452	17,270
Value ³ thousands	\$786,125	\$817,893	\$852,113	\$901,549	\$890,482
Average value per ton	\$49.96	\$47.96	\$49.68	\$51.66	\$51.56
Lime sold	13,105	14,736	15,016	15,448	15,265
Lime used	2,628	2,317	2,135	2,004	2,005
Exports ⁴	13	15	32	44	42
Imports for consumption ⁴	178	210	218	173	174
Consumption, apparent ⁵	15,898	17,248	17,337	17,581	17,402
World: Production	[†] 139,883	[†] 147,965	[†] 153,149	[†] 148,268	[†] 146,426

¹Estimated. ²Preliminary. ³Revised.

⁴Excludes regenerated lime. Excludes Puerto Rico.

⁵Data may not add to totals shown because of independent rounding.

⁶Selling value, f.o.b. plant, excluding cost of containers.

⁷Bureau of the Census.

⁸Calculated by sold or used plus imports minus exports.

**TABLE 2
TYPICAL ANALYSES OF
COMMERCIAL QUICKLIMES**

Component	High-calcium quicklimes, range, ¹ percent		Dolomitic quicklimes, range, ¹ percent	
	CaO	93.25	-98.00	55.50
MgO	.30	-2.50	37.60	-40.80
SiO ₂	.20	-1.50	.10	-1.50
Fe ₂ O ₃	.10	-.40	.05	-.40
Al ₂ O ₃	.10	-.50	.05	-.50
H ₂ O	.10	-.90	.10	-.90
CO ²	.40	-1.50	.40	-1.50

¹The values given in this range do not necessarily represent minima and maxima percentages.

Source: "Chemical Lime Facts," National Lime Association.

**TABLE 3
TIME-VALUE RELATIONSHIPS
FOR LIME¹**

Year	Average annual value, dollars per ton	
	Actual value ²	Based on constant 1991 dollars
1972	16.78	50.60
1973	17.42	49.35
1974	22.02	57.38
1975	27.46	65.30
1976	30.19	67.54
1977	33.50	74.30
1978	36.76	71.33
1979	41.26	73.70
1980	44.50	72.62
1981	47.01	69.71
1982	49.47	69.07
1983	51.10	68.56
1984	51.12	67.73
1985	51.69	64.06
1986	52.50	63.39
1987	50.11	58.63
1988	48.12	54.19
1989	49.83	53.78
1990	51.77	53.65
1991	51.73	51.73

¹Includes Puerto Rico.

²The average value of lime sold or used by producers, f.o.b. plant, excluding cost of containers.

TABLE 4
LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE¹

State	1990					1991				
	Plants	Hydrated (thousand short tons)	Quicklime (thousand short tons)	Total ² (thousand short tons)	Value (thousands)	Plants	Hydrated (thousand short tons)	Quicklime (thousand short tons)	Total ² (thousand short tons)	Value (thousands)
Alabama	4	154	1,372	1,526	\$70,816	4	149	1,361	1,510	\$75,506
Arizona	3	W	W	W	W	3	W	W	W	W
Arkansas, Louisiana, Oklahoma	3	48	205	254	15,143	3	40	201	241	13,658
California	10	51	295	345	19,425	10	49	258	307	20,389
Colorado, Nevada, Wyoming	9	W	W	464	29,968	9	W	W	531	31,465
Oregon and Washington	4	W	W	406	23,046	4	26	285	311	22,870
Idaho	3	—	W	W	W	3	—	W	W	W
Illinois, Indiana, Missouri	8	530	3,174	3,704	173,559	8	529	2,961	3,490	169,687
Iowa, Nebraska, South Dakota	5	W	W	264	14,014	5	W	W	287	15,153
Kentucky, Tennessee, West Virginia	5	129	1,867	1,996	109,685	5	124	1,922	2,047	102,565
Massachusetts	2	W	W	W	W	2	W	W	W	W
Michigan	8	W	W	622	30,898	8	32	581	613	30,959
Minnesota and Montana	7	—	W	W	W	7	—	W	W	W
North Dakota	3	—	82	82	4,623	3	—	98	98	5,360
Ohio	9	W	W	1,884	92,817	9	W	W	1,783	85,976
Pennsylvania	10	345	1,280	1,626	92,557	10	309	1,386	1,695	95,328
Puerto Rico	1	29	—	29	3,483	1	30	—	30	4,440
Texas	8	314	1,024	1,337	76,181	7	481	892	1,373	69,400
Utah	3	W	W	354	18,878	3	W	W	325	18,634
Virginia	5	174	672	846	39,784	5	150	675	825	39,612
Wisconsin	4	119	342	461	24,608	4	149	387	536	23,226
Other ³	(⁴)	448	4,825	1,279	65,547	(⁴)	352	3,873	1,299	70,694
Total²	114	2,341	15,140	17,481	905,032	113	2,420	14,880	17,300	894,922

¹W Withheld to avoid disclosing company proprietary data; included with "Other."

²Excludes regenerated lime. Includes Puerto Rico.

³Data may not add to totals shown because of independent rounding.

⁴Includes data indicated by the symbol W.

⁵Included with data for each individual State.

TABLE 5
LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES,¹ BY
SIZE OF PLANT

Size of plant	1990			1991		
	Plants	Quantity (thousand short tons)	Percent of total	Plants	Quantity (thousand short tons)	Percent of total
Less than 10,000 tons	15	96	(²)	10	70	(²)
10,000 to 25,000 tons	18	317	2	22	357	2
25,000 to 50,000 tons	13	472	3	15	562	3
50,000 to 100,000 tons	16	1,168	7	15	1,159	7
100,000 to 200,000 tons	21	2,990	17	19	2,579	35
200,000 to 400,000 tons	23	6,298	36	24	6,050	37
More than 400,000 tons	8	6,140	35	8	6,523	38
Total ³	114	17,481	100	113	17,300	100

¹Excludes regenerated lime. Includes Puerto Rico.

²Less than 1/2 unit.

³Data may not add to totals shown because of independent rounding.

TABLE 6
DESTINATION OF SHIPMENTS OF LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand short tons)

State	1990			1991		
	Quicklime	Hydrated lime	Total ²	Quicklime	Hydrated lime	Total ²
Alabama	589	38	627	624	32	656
Alaska	3	—	3	1	1	2
Arizona	254	59	312	271	59	329
Arkansas	170	27	197	149	26	175
California	521	120	640	475	96	571
Colorado	80	15	95	77	27	104
Connecticut	15	6	21	21	7	28
Delaware	14	2	17	13	5	19
District of Columbia	17	38	55	17	37	54
Florida	369	19	388	376	25	401
Georgia	238	70	308	278	77	355
Idaho	124	2	126	167	3	170
Illinois	639	183	822	603	176	779
Indiana	1,514	31	1,545	1,420	35	1,455
Iowa	79	29	107	73	26	99
Kansas	73	18	92	75	19	94
Kentucky	502	45	547	388	40	428
Louisiana	325	105	431	250	95	345
Maine	—	—	—	—	1	1
Maryland	135	19	154	183	20	203
Massachusetts	145	9	154	120	12	132
Michigan	1,043	41	1,085	1,037	76	1,112
Minnesota	246	16	262	258	15	274
Mississippi	199	6	205	196	9	205
Missouri	196	67	263	162	67	228
Montana	206	13	218	200	18	218
Nebraska	61	13	74	61	14	75
Nevada	269	57	327	294	36	330
New Hampshire	—	—	—	2	—	2
New Jersey	106	24	130	197	26	223
New Mexico	166	21	187	176	28	203
New York	73	42	115	80	37	117
North Carolina	201	43	244	198	43	241
North Dakota	187	4	192	218	5	223
Ohio	1,453	147	1,600	1,581	148	1,729
Oklahoma	121	14	134	131	20	152
Oregon	104	33	136	128	27	155
Pennsylvania	1,900	265	2,165	1,740	201	1,941
Rhode Island	7	1	8	7	2	9
South Carolina	191	25	216	175	26	201
South Dakota	45	2	47	31	2	33
Tennessee	214	61	275	207	55	262
Texas	1,010	311	1,321	932	469	1,401
Utah	147	9	157	140	16	156
Vermont	—	—	—	—	2	2

See footnotes at end of table.

TABLE 6—Continued

DESTINATION OF SHIPMENTS OF LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand short tons)

State	1990			1991		
	Quicklime	Hydrated lime	Total ²	Quicklime	Hydrated lime	Total ²
Virginia	150	89	239	153	58	211
Washington	304	22	327	205	16	221
West Virginia	454	61	515	444	61	505
Wisconsin	128	47	175	154	52	206
Wyoming	95	22	116	106	25	131
Total ²	<u>15,082</u>	<u>2,290</u>	<u>17,376</u>	<u>14,794</u>	<u>2,373</u>	<u>17,166</u>
Puerto Rico	—	24	24	(³)	23	23
Canada	39	17	56	57	15	72
Other ⁴	17	5	44	29	7	36
Total	<u>56</u>	<u>46</u>	<u>102</u>	<u>86</u>	<u>47</u>	<u>132</u>
Grand total ²	<u>15,140</u>	<u>2,336</u>	<u>17,481</u>	<u>14,880</u>	<u>2,420</u>	<u>17,300</u>

¹Excludes regenerated lime.²Data may not add to totals shown because of independent rounding.³Less than 1/2 unit.⁴Includes other countries and U.S. possessions.

TABLE 7
LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE¹

(Thousand short tons and thousand dollars)

Use	1990				1991			
	Sold	Used	Total ²	Value	Sold	Used	Total ²	Value
Agriculture	49	—	49	2,898	53	—	53	3,741
Chemical and industrial:								
Alkalies	W	W	106	5,170	W	W	88	4,372
Aluminum and bauxite	155	—	155	8,122	160	—	160	8,459
Copper ore concentration	W	W	373	17,540	W	W	409	19,691
Food products, animal or human	21	—	21	1,171	22	—	22	1,224
Glass	99	—	99	5,022	168	—	168	8,389
Magnesia from seawater or brine	W	W	653	31,987	W	W	577	28,873
Oil well drilling	12	—	12	693	12	—	12	633
Oil and grease	W	W	19	1,283	W	W	W	W
Ore concentration, other	331	—	331	15,940	378	—	378	18,135
Paper and pulp	W	W	1,265	64,901	W	W	1,240	59,509
Precipitated calcium carbonate	W	W	254	11,718	W	W	298	15,370
Steel, BOF	W	W	4,034	193,254	W	W	4,156	198,486
Steel, electric	W	W	974	50,698	920	—	920	47,651
Steel, open-hearth	122	—	122	5,856	48	—	48	2,300
Sugar refining	30	627	657	35,596	29	737	765	44,476
Tanning	26	—	26	1,548	21	—	21	1,374
Other ³	8,919	1,178	2,419	131,599	7,844	1,083	2,158	109,928
Total ²	9,716	1,805	11,521	582,100	9,602	1,820	11,420	568,870
Construction:								
Soil stabilization	672	—	672	36,188	714	—	714	39,714
Finishing lime	160	—	160	14,708	106	—	106	7,840
Mason's lime	W	W	254	17,932	W	W	185	10,404
Other ⁴	500	—	295	12,217	297	—	297	22,508
Total ²	W	W	1,381	81,046	1,117	W	1,302	80,466
Environmental:								
Acid water, mine or plant	285	—	285	16,120	346	—	346	20,756
Sewage treatment	467	—	467	22,014	521	—	521	28,435
Flue gas sulfur removal	1,673	—	1,673	89,694	1,725	—	1,725	84,390
Water purification	1,072	—	1,072	50,271	1,138	—	1,138	58,890
Other ⁵	647	10	657	33,900	450	5	455	23,641
Total ²	4,143	10	4,154	211,999	4,180	5	4,185	216,112
Refractory lime (dead-burned dolomite)	W	W	377	26,988	W	W	339	25,736
Grand total ²	15,476	2,004	17,481	905,032	15,295	2,005	17,300	894,922

W Withheld to avoid disclosing company proprietary data.

¹Excludes regenerated lime. Includes Puerto Rico.

²Data may not add to totals shown because of independent rounding.

³Includes briquetting, brokers, calcium carbide, chrome, citric acid, commercial hydrators, desiccants, ferroalloys, fiberglass, glue, insecticides, ladle desulfurizing, magnesium metal, metallurgy, pelletizing, pharmaceuticals, petrochemicals, rubber, silica brick, soap wire drawing, and uses indicated by symbol W in "Chemical and industrial" lime only.

⁴Includes asphalt anti-stripping.

⁵Includes industrial solid waste treatment, industrial wastewater treatment, scrubber sludge solidification and other environmental uses.

**TABLE 8
U.S. EXPORTS OF LIME**

	Quantity (short tons)	Value ¹ (thousands)
1987	12,644	\$2,971
1988	14,908	3,113
1989	32,241	3,893
1990	44,287	4,755
1991	41,975	4,659

¹Customs value.

Source: Bureau of the Census.

**TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF LIME**

	Hydrated lime		Other lime		Total	
	Quantity (short tons)	Value ¹ (thousands)	Quantity (short tons)	Value ¹ (thousands)	Quantity (short tons)	Value ¹ (thousands)
1988	54,419	\$4,031	155,497	\$8,541	209,916	\$12,572
1989	36,952	2,219	180,704	9,749	217,656	11,968
1990	29,920	2,147	143,277	8,245	173,197	10,392
1991	26,588	1,977	147,339	9,091	173,927	11,068

¹Customs value.

Source: Bureau of the Census.

TABLE 10
**QUICKLIME AND HYDRATED LIME, INCLUDING DEAD-BURNED
 DOLOMITE: WORLD PRODUCTION, BY COUNTRY¹**

(Thousand short tons)

Country ²	1987	1988	1989	1990	1991 [*]
Algeria [*]	45	45	45	45	45
Australia [*]	1,210	1,210	1,650	1,650	1,650
Austria	1,519	1,703	1,788	[*] 1,804	1,650
Belgium	1,944	2,086	[*] 2,100	[*] 2,220	2,210
Botswana	(^o)	(^o)	[*] (^o)	[*] (^o)	—
Brazil	5,842	6,063	6,316	[*] 5,401	6,060
Bulgaria	1,409	1,570	1,581	[*] 1,542	1,430
Burundi	(^o)	(^o)	(^o)	(^o)	(^o)
Canada	[*] 2,568	2,776	[*] 3,100	[*] 2,650	2,650
Chile [*]	1,100	1,320	1,430	1,430	1,320
China [*]	12,100	14,300	17,600	18,700	20,400
Colombia [*]	1,430	1,430	1,430	1,430	1,430
Costa Rica [*]	11	11	25	[*] 40	40
Cuba	204	197	[*] 200	[*] 220	200
Cyprus	8	8	[*] 8	[*] 8	8
Czechoslovakia	3,569	3,650	3,688	[*] 3,439	3,300
Denmark (sales)	132	148	[*] 149	[*] 140	150
Dominican Republic [*]	40	40	39	39	40
Egypt [*]	105	105	105	105	105
Ethiopia	6	4	[*] 4	[*] 4	4
Fiji Islands	—	—	[*] 2	—	—
Finland (sales)	[*] 299	[*] 287	[*] 247	[*] 248	250
France [*]	<u>3,300</u>	<u>[*]3,405</u>	<u>3,400</u>	<u>3,300</u>	<u>3,300</u>
Germany, Federal Republic of:					
Eastern states	3,724	3,835	[*] 3,750	[*] 3,300	NA
Western states	6,736	7,497	7,753	[*] 7,598	NA
Total	<u>10,460</u>	<u>11,332</u>	<u>11,503</u>	<u>10,898</u>	<u>10,270</u>
Guatemala	88	79	87	[*] 83	80
Hungary	916	938	968	916	920
India [*]	770	830	870	880	940
Iran [*]	700	700	700	700	700
Ireland	85	107	123	[*] 110	110
Israel [*]	143	[*] 143	143	143	143
Italy [*]	4,292	[*] 4,300	[*] 4,300	[*] 4,240	3,970
Jamaica	99	88	[*] 100	[*] 100	100
Japan (quicklime only)	7,435	8,516	9,354	[*] 9,902	9,870
Jordan	4	3	3	[*] 6	6
Kenya	29	[*] 28	35	[*] 13	11
Korea, Republic of [*]	220	250	250	250	260
Kuwait [*]	69	72	72	55	55
Lebanon [*]	11	11	11	11	11
Libya [*]	290	290	290	290	290
Malawi [*]	3	3	3	3	3
Malta [*]	6	6	6	6	6
Martinique [*]	6	6	6	6	6
Mauritius [*]	8	8	8	8	8
Mexico	6,889	6,614	[*] 6,610	[*] 6,610	7,170

See footnotes at end of table.

TABLE 10—Continued
**QUICKLIME AND HYDRATED LIME, INCLUDING DEAD-BURNED
 DOLOMITE: WORLD PRODUCTION, BY COUNTRY¹**

(Thousand short tons)

Country ²	1987	1988	1989	1990	1991 [*]
Mongolia [*]	¹ 126	¹ 135	¹ 105	¹ 110	100
Mozambique [*]	6	6	6	6	6
Nepal	1	23	45	[*] 50	55
New Zealand [*]	175	165	110	110	100
Nicaragua [*]	4	4	4	⁴	4
Norway [*]	110	110	110	110	110
Paraguay	102	94	114	¹ 110	110
Peru [*]	⁵ 14	14	14	14	14
Philippines	² 0	4	⁵	¹ 4	11
Poland	4,701	4,883	4,873	³ ,520	3,420
Portugal [*]	220	220	220	220	220
Romania [*]	4,000	3,900	3,600	³ ,530	3,310
Saudi Arabia [*]	13	13	13	13	13
South Africa, Republic of (sales)	1,744	2,112	2,138	2,018	⁵ 1,946
Spain	1,300	1,300	1,380	1,320	1,320
Sweden	650	740	⁷ 40	⁷ 20	700
Switzerland [*]	44	46	44	44	44
Taiwan	116	117	110	¹ 110	110
Tanzania [*]	3	3	3	3	3
Tunisia [*]	720	720	720	⁷ 40	720
Turkey [*]	1,200	1,600	1,500	1,800	1,800
Uganda [*]	1	1	1	1	1
U.S.S.R.	33,203	33,705	33,486	³⁰ ,860	28,700
United Arab Emirates [*]	50	50	50	50	50
United Kingdom [*]	3,100	3,100	3,100	2,870	2,870
United States including Puerto Rico (sold or used by producers)	15,758	17,077	17,178	17,481	⁵ 17,303
Uruguay	14	11	13	¹ 3	13
Venezuela [*]	2	2	2	2	2
Yugoslavia	2,754	2,754	² ,653	² ,340	1,760
Zaire	109	111	110	110	110
Zambia	259	263	353	³ 30	330
Total	¹ 139,883	¹ 147,965	¹ 153,149	¹ 148,268	146,426

^{*}Estimated. ¹Revised. NA Not available.

²Table includes data available through June 12, 1992.

³Lime is produced in many other countries besides those listed. Argentina, Iraq, Pakistan, and Syria are among the more important countries for which official data are not available.

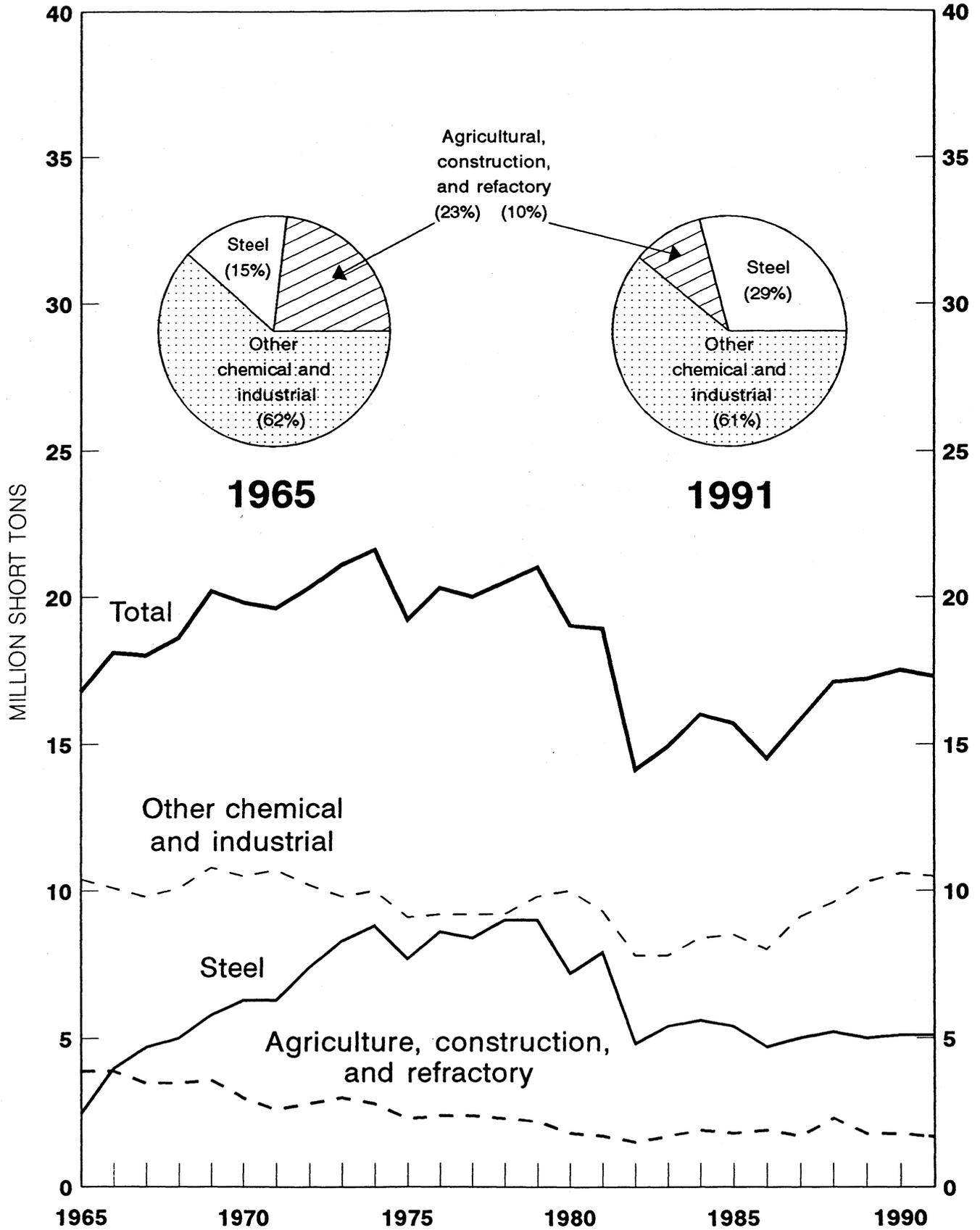
⁴Less than 1/2 unit.

⁵Revised to zero.

⁶Reported figure.

⁷Includes hydraulic lime.

FIGURE 1
TRENDS IN MAJOR USES OF LIME



LITHIUM

By Joyce A. Ober

Mrs. Ober, a physical scientist with 14 years industry and U.S. Bureau of Mines experience, has been the commodity specialist for lithium since 1986. Domestic survey data were prepared by Carleen Militello, statistical assistant; and international data tables were prepared by staff, Branch of Data Collection and Coordination.

The United States led the world in lithium mineral and compound production and consumption. Domestic estimated consumption decreased slightly for the first time in 4 years; world production has risen steadily. Domestic producers announced modest price increases for the fifth consecutive year.

Because lithium is electrochemically reactive and has other unique properties, there are many commercial lithium products. Producers sold lithium as mineral concentrate, brine, compound, or metal depending on the end use. Most lithium compounds were consumed in the production of ceramics, glass, and primary aluminum.

DOMESTIC DATA COVERAGE

The U.S. Bureau of Mines collects domestic production data for lithium from a voluntary survey of U.S. operations. The two U.S. companies responded to the survey, representing 100% of total production. Production and stock data were withheld from publication to avoid disclosing company proprietary data. (See table 1.)

ANNUAL REVIEW

Legislation and Government Programs

The Department of Energy (DOE) planned to offer portions of its 36-million-kilogram stock of lithium hydroxide monohydrate for sale. The DOE stocks were excess from a weapons program that used the lithium to make tritium, a compound necessary for

nuclear fission reactions. The stockpile originally contained about 42,000 metric tons of material, from which about 75% of the lithium 6 isotope had been removed. This material possibly contained 8 to 9 parts per million of mercury, which could present an environmental hazard. DOE had planned to offer the lithium hydroxide for sale since 1989, but delayed the disposal until an environmental impact study was complete. A final decision about disposal had not been made at yearend, and no material was offered for sale in 1991.

Production

The two companies that produced lithium in the United States in 1991 did so from two different types of deposits. Both firms mined spodumene, (a lithium-aluminum-silicate mineral) from large hard-rock deposits in North Carolina using open pit methods. One company recovered lithium from geothermal brine deposits in Nevada.

Lithium carbonate is the most important lithium compound produced from both types of deposits. Spodumene was a major raw material for the production of lithium carbonate in North Carolina, and small amounts of spodumene concentrate were produced for sale. Extracting lithium from spodumene entails an energy-intensive chemical recovery process.

After mining, spodumene is crushed and undergoes a flotation beneficiation process to produce concentrate. Concentrate is heated to 1,075° C to 1,100° C, changing the molecular structure of the mineral, making it more

reactive to sulfuric acid. A mixture of finely ground, converted spodumene and sulfuric acid is heated to 250° C, forming lithium sulfate. Water is added to the mixture to dissolve the lithium sulfate. Insoluble portions of ore are then removed by filtration. The purified lithium sulfate solution is treated with soda ash, forming insoluble lithium carbonate that precipitates from solution. The carbonate is separated and dried for sale or use by the producer as feedstock in the production of other lithium compounds.

Production of lithium carbonate from brine in Nevada is much less energy intensive than production from spodumene. Brines enriched in lithium chloride—averaging about 300 parts per million when operation began in 1966—are pumped from the ground and progress through a series of evaporation ponds. Over the course of a year to 18 months, concentration of the brine increases to 6,000-parts-per-million lithium through solar evaporation. When the lithium chloride reaches optimum concentration, the liquid is pumped to a recovery plant and treated with soda ash, precipitating lithium carbonate. The carbonate is then removed through filtration, dried, and shipped.

FMC Corp., Lithium Div., formerly Lithium Corp. of America (Lithco), mined spodumene from pegmatite dikes near Bessemer City, NC. The company produced lithium carbonate and a full range of downstream compounds, including lithium metal and some organic lithium compounds, at a chemical plant near the mine. The company completed

Cyprus Foote Mineral Co. produced about 6,400 tons of lithium carbonate from its brine deposit in Silver Peak, NV, and about 8,300 tons of spodumene concentrate at its mine in Kings Mountain, NC.¹ It operated processing facilities for downstream lithium products and metal in Kings Mountain, Exton, PA, Sunbright, VA, and New Johnsonville, TN. The company continued to maintain its lithium carbonate plant at Kings Mountain on a care-and-maintenance status as it had since mid-1986.

Consumption and Uses

The aluminum, ceramics and glass, lubricating grease, and synthetic rubber industries consumed most of the lithium minerals and chemicals. These markets were primarily related to transportation; i.e., the aircraft and automotive industries. Industrial and consumer applications also used ceramics and glass. Estimated domestic consumption decreased about 4% in 1991. Ceramics and glass production and aluminum smelters were the largest consumers of lithium carbonate and lithium concentrates in the United States. In other countries, aluminum producers consume little lithium carbonate.

Lithium carbonate and mineral concentrate additions in ceramics and glass manufacturing processes lower process melting points, reduce the coefficient of thermal expansion and the viscosity, and eliminate the use of more toxic chemicals. The manufacture of thermal-shock-resistant cookware (pyroceramics) consumed the majority of lithium used in the ceramics and glass industry domestically. The manufacture of black and white television picture tubes consumed significant amounts of lithium concentrates overseas. Low-iron spodumene and petalite (another lithium mineral) were a source of lithium used to improve the physical properties of container and bottle glass and as a source of alumina, another important component of the glass. Glass manufacturers used lithium in container and bottle glass, enabling them to produce lighter weight, thinner walled products.

Aluminum producers added lithium carbonate to cryolite baths in aluminum potlines. The chemistry of the potline converts it to lithium fluoride, lowering the melting point of the bath, allowing a lower operating temperature for the potline, and increasing the electrical conductivity of the bath. Operators used these factors to increase production or reduce power consumption.

The multipurpose grease industry was the third largest end use for lithium in 1991. Lithium hydroxide monohydrate was the compound used for the production of lithium lubricants. Lithium-base greases are favored for their retention of lubricating properties over a wide temperature range; good resistance to water, oxidation, and hardening; and formation of a stable grease on cooling after melting. These greases continued to be utilized in military, industrial, automotive, aircraft, and marine applications.

Almost all major battery manufacturers marketed some type of lithium batteries, and research and development continued for further substitution in applications that implement more conventional alkaline batteries. These batteries represent a growth area for lithium consumption, but sales have not increased as rapidly as originally expected. Eastman Kodak Co., the first company to offer a lithium battery to the U.S. consumer market, chose to discontinue production owing to low sales. Kodak's 9-volt lithium battery had at least twice the life of a comparable alkaline battery, but consumers were not willing to pay the higher price.

Lithium batteries offer improved performance over alkaline batteries at a slightly higher cost. They were used in watches, microcomputers, and cameras, and, more recently, in small appliances, electronic games, and toys. The military purchased large and small lithium batteries for a variety of military applications. The Galileo spacecraft, launched in October of 1989 for its 6-year trip to explore the atmosphere of Jupiter, contained lithium-sulfur dioxide batteries to power its scientific instruments when it reaches its destination. Recent modifications to the

lithium-sulfur dioxide battery have extended the life of the batteries to at least 10 years with little or no reduction of performance.

Aircraft manufacturers in several countries have designed new aircraft using aluminum-lithium alloys for wing and fuselage skin or structural members. Use of aluminum-lithium alloys can reduce the weight of the aircraft by more than 10%, allowing significant fuel savings during the life of the aircraft. The alloys, which are 2% to 3% lithium by weight, are attractive to the aircraft and aerospace industry because of their reduced density and superior corrosion resistance compared to those of conventional aluminum alloys. These alloys face direct competition, however, from composite materials consisting of boron, graphite, or aramid fibers imbedded in polymers.

Butyllithium, a catalyst in synthetic rubber production and the most important organic lithium compound, was one market area that was growing. Both domestic companies recently increased capacity for production of this compound. Small quantities of other lithium compounds were important to many industries. Lithium chloride and lithium bromide were used in industrial air-conditioning systems, commercial dehumidification systems, and in the production of sophisticated textiles. Sanitizers for swimming pools, commercial glassware, and public restrooms contained lithium hypochlorite, as did dry bleach for commercial laundries. Patients diagnosed as suffering from manic-depressive mental disorders may take medication containing a pharmaceutical grade of lithium carbonate. Lithium metal was used as a scavenger to remove impurities from copper and bronze, and anhydrous lithium chloride was used as a component in fluxes for hard-to-weld metals such as steel alloys and aluminum.

Prices

Both domestic companies increased prices for almost all lithium products for the fifth consecutive year. Prices

Both domestic companies increased prices for almost all lithium products for the fifth consecutive year. Prices averaged about 5% higher in 1991 than in the previous year. The close balance between supply and demand worldwide kept prices in step with inflation. Although installed production capacity remained in excess of demand, Cyprus Foote's chemical plant at Kings Mountain remained inactive, helping to keep supply and demand balanced sufficiently to maintain the trend. (See table 2.)

Foreign Trade

Total U.S. exports of lithium compounds were about 8% lower in 1991 than they were in 1990. Exports of lithium carbonate increased slightly, but lithium hydroxide and lithium metal exports decreased. The majority of U.S. exports of lithium compounds were to the Federal Republic of Germany, Japan, and the United Kingdom. Imports of lithium compounds reported by the U.S. Bureau of the Census decreased 25%. Cyprus Foote Mineral Co. owns a lithium brine operation in Chile; 99% of all lithium imports was from this source. Lithium ore concentrates from Canada and Zimbabwe were consumed in the United States, but no import statistics were available. (See tables 3 and 4.)

World Review

A small number of countries throughout the world produced lithium ore and brine. The United States produced the most lithium; significant quantities also were produced in Australia, Canada, Chile, China, Portugal, the U.S.S.R., and Zimbabwe. Argentina, Brazil, and Namibia produced smaller quantities; production primarily consisted of concentrates. Rwanda, the Republic of South Africa, and Zaire are past producers of concentrates. Pegmatites containing lithium minerals have been identified in Austria, France, India, Ireland, Mozambique, Spain, and Sweden, but economic conditions have not favored development of the deposits. Lithium has been identified in subsurface

brines in Argentina, Bolivia, China, and Israel. Companies in France, the Federal Republic of Germany, Japan, and the United Kingdom produced downstream lithium compounds from imported lithium carbonate.

Capacity.—The data in table 5 are rated capacity for mines and refineries as of December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgement of the author, can be brought into production within a short period of time with minimum capital expenditure. Any restrictions to capacity utilization related to legal, political, or environmental restraints have been footnoted.

Lithium presented special problems during compilation of production capacities for different operations. Ore concentrate products are not comparable to lithium carbonate. Lithium carbonate was the primary compound produced at lithium chemical plants and the compound from which all other lithium chemicals were produced. Because even high-grade ore products usually contained less than 4% lithium and lithium carbonate contains almost 20% lithium, production capacities reported in tons per year represent large differences in the actual lithium content of the product. For that reason, capacities were reported based on the lithium content of the products also known as contained lithium.

Capacity from the Cyprus Foote's Kings Mountain plant is still listed in the table, but this capacity has been idle since mid-1986 and is not expected to reopen in the near future. (See table 5.)

Argentina.—Small annual production occurred from pegmatite deposits in the Catamarca and San Luis Provinces.

Spodumene reserves are estimated at 140,000 tons of 0.7% lithium.

Brine deposits have also been identified. FMC signed an agreement with the Argentine Government in 1986 to explore the Salar del Hombre Muerto in Catamarca Province. Estimates of geologic resources have been reported at 130,000 tons of lithium contained in brine ranging from 0.22 to 1.08 grams per liter. The Salar del Rincon also was identified as a lithium resource in the Salta Province.²

Australia.—Lithium Australia Ltd. (LAL), subsidiary of the Gwalia Group, mined high-grade, low-iron spodumene at its mine in Greenbushes, Western Australia. LAL produced two spodumene concentrate products through a flotation process for sale to the ceramics and glass industry. The majority of the company's spodumene concentrate was used in the manufacture of black and white television picture tube glass and pyroceramics in the Pacific rim countries and Europe. Glass-grade concentrate with lower lithium content was marketed in the same countries for consumption in container glass.

LAL was awarded the Outstanding Export Achievement Award in 1990 by the Western Australia Department of Trade Development for its growth in export sales and success in establishing a new export industry for Australia.

Bolivia.—The Government of Bolivia and FMC reached an agreement for a joint-venture operation in the Salar de Uyuni, a lithium brine deposit considered to be a national asset. FMC's plans included an exploration program and a plant for recovery of lithium carbonate from the evaporated brines. Extreme political pressures in 1990 prompted the Government of Bolivia to cancel the accord and issue a call for international bids. FMC was ultimately awarded the contract.

FMC will produce 10,000 tons per year of lithium carbonate over 40 years under the terms of the contract. A feasibility study should begin in mid-1992 and be

completed within 2 years. FMC is expected to invest \$92 million for the feasibility study and construction of the lithium carbonate plant.³

Preliminary studies of the Salar de Uyuni, which is more than 3,600 meters above sea level, indicated resources of 5.5 million tons of lithium, 110 million tons of potassium, and 3.2 million tons of boron. The salar may be the world's largest salt flat.⁴

Brazil.—Brazil has produced small quantities of lithium minerals for almost 30 years. Companhia Brasileira de Lítio built a plant in Aquas Verhelhas, Minas Gerais, to produce 1,000 tons of lithium hydroxide and 200 tons of lithium carbonate.

Canada.—Tantalum Mining Corp. (Tanco) mined spodumene concentrate at its mine near Bernic Lake in southeastern Manitoba. Since mining began in 1984, Tanco has grown to become the largest supplier of lithium concentrates to the U.S. ceramics and glass industry. The Canadian spodumene was similar to the material mined in Australia (high-grade spodumene with very low iron content), making the concentrates ideal for direct application in the ceramics and glass industry.

A number of other lithium deposits have been identified throughout Canada. A pegmatite deposit was operated in Quebec for about 10 years starting in 1955, but there has been no production since then. The largest demonstrated resources occur in the Yellowknife deposits in the Northwest Territories.⁵ Although these are large deposits, the location is too remote for production to be feasible in the foreseeable future.

Chile.—Cyprus Foote Mineral Co. is the sole owner of its lithium brine operation at the Salar de Atacama, Sociedad Chilena de Lítio Ltda., having bought the remaining interest from the Chilean Government in 1989. Cyprus Foote produced lithium carbonate from the brines from this Salar, which has been worked since 1984. The project

originated as a joint venture between Foote and Corporación de Fomento de la Producción (CORFO), a Chilean Government agency. Production capacity for lithium carbonate increased steadily from a 6,300-ton-per-year capacity to reach the current level of almost 12,000 tons per year.

The possibility of a second lithium operation at the Salar de Atacama had been under investigation. Minera Salar de Atacama Ltda. (MINSAL), the consortium formed by AMAX Exploration Inc. (United States), CORFO, and Molibdenos y Metales S.A. (Chile), completed studying the feasibility of developing another lithium operation on the Salar in 1988. Evaluations of the results were analyzed, and AMAX announced its decision to sell its portion of the project in 1990.⁶

China.—Lithium pegmatite and brine deposits are worked in China, but specific information about any of the deposits is not available. Lithium carbonate and hydroxide from China has been marketed in the Federal Republic of Germany, Japan, and the Netherlands.

France.—Lithium metal is produced by Metaux Speciaux SA in Plombières St. Marcel, Savoie. The plant has the capacity to produce 25 tons per year of very high-purity metal for use in aluminum-lithium alloys. The company is a subsidiary of Pechiney.⁷

Germany, Federal Republic of.—The Federal Republic of Germany has been a major producer of lithium compounds, although no lithium ore is mined there. Chemetall GmbH, a member of the Metallgesellschaft Group AG, produced downstream lithium compounds and metal from lithium carbonate imported from the United States and other countries. The company's lithium operations are in Langelshelm.

Japan.—Japan is a major consumer of lithium compounds, some of which it produces from imported lithium carbonate. FMC and the Honjo Chemical

Co. have a joint venture, Asia Lithium Corp., to market FMC's lithium products in Japan. Asia Lithium was constructing a 100-ton-per-year battery-grade lithium metal operation in Kagawa. Yahagi Iron Co. also produced lithium metal in Nagoya.

Namibia.—Southwest Africa (SWA) Lithium Mines produced petalite concentrate at its Rubicon Mine near Karibib. Low-grade ores were beneficiated through a flotation process, while high-grade ores were handpicked. Small amounts of two other lithium minerals, lepidolite (lithia mica) and amblygonite (lithia alumina phosphate), were other products. The Federal Republic of Germany imported most of these concentrates. High-grade lepidolite was handpicked at the company's Helicon Mine for export to Western Europe and Japan.⁸

Portugal.—Lithium has been produced inconsistently in Portugal. Recent reports indicate that production has gone up significantly in recent years, but details on the operations and markets are not available. Past lithium production has been lepidolite.

United Kingdom.—Lithium Corp. of Europe operates a facility in Bromborough, Mersyside, for the production of lithium metal and butyllithium. Lithium carbonate and lithium chloride are imported from its parent company, FMC.

U.S.S.R.—Lithium ores, compounds, and metal were produced in the U.S.S.R., but no details were available.

Zimbabwe.—Bikita Minerals Ltd. mined petalite, another lithium mineral, near Masvingos. Although the ore reserves were becoming depleted, installation of a dense-media separator made it possible to recover lithium in the form of petalite averaging about 4.4% lithium oxide from a stockpile of previously rejected material. This extended the estimated mine life 30 years.

Hand sorting, the method used since the mining began in 1916, amassed a stockpile of more than 1 million tons that could be recovered with a significant savings in mining costs after installation of the new device. Hand sorting continued to be used only for special small orders of minerals other than petalite.⁹ (See table 6.)

OUTLOOK

The aluminum industry experienced a slowdown in 1984, and, as a result, domestic lithium consumption decreased dramatically that year. Lithium consumption has increased slightly since that time. This increase was primarily due to the economic recovery of the aluminum industry as well as increased demand for lithium compounds and minerals in the ceramics and glass and synthetic rubber industries. Similar increases are expected for the future.

Demand for butyllithium is expected to continue to increase, and both domestic producers have increased production capacity to meet that demand. Demand for lithium metal for batteries and alloys should increase, but total consumption of the metal will remain small in comparison to the demand for lithium chemicals. Markets should remain relatively stable with slight growth, although new applications for mineral concentrates could increase demand for those materials significantly in the next few years. Lithium demand could increase dramatically if any of the new technology areas such as nuclear fusion were perfected. This is not expected to occur within the remainder of this century and probably not within the next 25 years.

¹Cyprus Mineral Co. 1991 10-K Report, p. 6.

²Roskill Information Services Ltd. (London). *The Economics of Lithium 1990*. 1990, pp. 29-30.

³Mining Journal (London). Uyuni Lithium for FMC. V. 318, No. 8166, 1992, p. 1.

⁴U.S. Embassy, La Paz, Bolivia. Lithium Corp. of America Signs Preliminary Contract to Exploit the Dalar of Uyuni. State Dep. Telegram 15280, Nov. 24, 1989, 2 pp.

⁵Bleiwas, D., and J. Coffman. *Lithium Availability—Market Economy Countries*. BuMines IC 9102, 1986, pp. 10-12.

⁶Fertilizer Markets. AMAX Potash Sale Closing Delayed. V. 1, No. 3, 1990, p. 1.

⁷Page 62 of work cited in footnote 2.

⁸Murray, R. *Namibia's Mineral Potential—Independence Brightens Development Prospects*. Ind. Miner. (London). No. 266, 1989, p. 87.

⁹Russell, A. *Bikita Minerals—35 Years on and Still Further Potential*. Ind. Miner. (London). No. 249, 1988, pp. 63-71.

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TABLE 2
DOMESTIC YEAREND PRODUCERS' AVERAGE PRICES
OF LITHIUM AND LITHIUM COMPOUNDS

	1990		1991	
	Dollars per pound	Dollars per kilogram	Dollars per pound	Dollars per kilogram
Lithium bromide, 54% brine:				
Truckload lots, delivered in drums	5.10	11.24	5.31	11.71
Lithium carbonate, technical:				
Truckload lots, delivered	1.83	4.03	1.91	4.21
Lithium chloride, anhydrous, technical: Truckload lots, delivered	4.31	9.50	4.53	9.99
Lithium fluoride	6.35	14.00	6.67	14.70
Lithium hydroxide monohydrate:				
Truckload lots, delivered	2.32	5.11	2.44	5.61
Lithium metal ingot, standard-grade: 1,000-pound lots, f.o.b.	30.00	66.14	31.50	69.46
Lithium sulfate, anhydrous	3.51	7.74	3.51	7.71
N-butyllithium in n-hexane (15%):				
Truckload lots, delivered	17.80	39.24	18.78	41.40

Sources: U.S. lithium producers and Chemical Marketing Report, v. 240, No. 1, Jan. 3, 1992, p. 38.

TABLE 3
U.S. EXPORTS OF LITHIUM CHEMICALS, BY COMPOUND AND
COUNTRY

Compound and country	1990		1991	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Lithium carbonate:				
Argentina	1,198	\$4,976	7,994	\$33,566
Australia	15,423	61,534	889	8,722
Belgium	19,958	52,096	158	4,537
Brazil	82,845	304,272	1,000	4,224
Canada	1,237,195	4,014,028	1,128,763	4,189,644
France	19,958	55,000	1,059	3,795
Germany, Federal Republic of	3,325,696	10,516,167	3,067,698	9,286,896
India	18,147	82,161	29,847	123,564
Italy	—	—	1,885	10,029
Japan	1,090,131	4,938,599	1,263,050	4,574,933
Korea, Republic of	87,454	312,484	109,819	355,154
Malaysia	371	9,965	—	—
Mexico	82,798	339,228	124,349	448,041
Netherlands	250,068	746,861	108,121	390,521
New Zealand	150	5,558	—	—
Singapore	—	—	2,173	16,638
South Africa, Republic of	16,164	66,284	—	—
Spain	31,558	253,288	—	—
Taiwan	—	—	15,957	53,023
United Kingdom	1,608,494	3,812,888	1,471,587	4,051,112

TABLE 3—Continued
U.S. EXPORTS OF LITHIUM CHEMICALS, BY COMPOUND AND COUNTRY

Compound and country	1990		1991	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Lithium carbonate—Continued:				
Venezuela	761,561	\$2,342,945	617,106	\$2,070,566
Total¹	8,649,169	27,918,334	7,951,455	25,624,965
Lithium carbonate U.S.P.²				
Austria	—	—	15	4,655
Australia	51,478	202,529	83,144	329,769
Colombia	—	—	2,289	24,911
El Salvador	—	—	—	—
Germany, Federal Republic of	35,021	117,900	2,794	37,622
India	3,050	17,503	11,498	49,524
Italy	—	—	20	3,750
Japan	243,060	814,426	932,004	3,233,933
Korea, Republic of	145,243	478,139	151,296	505,023
Mexico	10	6,578	38,043	77,160
Netherlands	1,479	3,000	—	—
New Zealand	699	10,430	—	—
South Africa, Republic of	3,200	12,640	3,554	17,220
Taiwan	176,502	547,222	181,560	653,922
United Kingdom	3,992	30,924	—	—
Venezuela	—	—	207,003	710,560
Total	663,734	2,241,291	1,613,219	5,648,049
Lithium hydroxide:				
Argentina	37,852	173,887	111,268	498,430
Australia	139,809	620,590	104,684	500,579
Bangladesh	1,000	4,812	—	—
Belgium	9,617	17,187	—	—
Brazil	204,783	919,565	302,289	1,414,466
Canada	66,080	313,149	34,168	168,448
Chile	34,890	157,575	22,400	105,892
Colombia	27,660	122,607	41,779	193,388
Ecuador	14,600	66,644	7,000	33,860
Egypt	142,327	631,480	8,800	40,066
Finland	—	—	17,500	47,740
Germany, Federal Republic of	292,293	1,007,909	321,523	1,372,859
Guinea	5,816	28,860	—	—
Hong Kong	—	—	100,802	186,480
India	234,390	1,459,325	225,016	988,190
Indonesia	—	—	37,196	190,476
Israel	10,993	54,187	26,901	141,752
Italy	60	6,680	—	—

See footnotes at end of table.

TABLE 3—Continued
U.S. EXPORTS OF LITHIUM CHEMICALS, BY COMPOUND AND COUNTRY

Compound and country	1990		1991	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Lithium hydroxide—Continued				
Japan	790,077	\$3,592,345	743,435	\$3,530,724
Korea, Republic of	156,592	614,326	216,723	906,048
Malaysia	1,996	10,282	—	—
Mexico	68,467	272,899	79,973	387,949
Morocco	—	—	359	12,103
Netherlands	45,304	185,209	5,017	29,053
New Zealand	3,999	20,067	—	—
Nigeria	15,966	66,880	—	—
Norway	—	—	24	9,177
Pakistan	16,400	76,292	32,622	66,690
Peru	5,098	23,009	7,000	31,640
Philippines	36,218	94,185	9,580	42,543
Poland	—	—	201	10,695
Saudia Arabia	—	—	55,321	111,504
Singapore	34,866	159,685	58,069	233,704
South Africa, Republic of	93,697	345,918	26,146	119,563
Sweden	79	56,800	—	—
Taiwan	—	—	25,001	118,225
Thailand	85,388	386,175	76,490	288,979
United Arab Emirates	6,985	31,108	—	—
United Kingdom	563,946	1,433,420	343,849	1,046,082
Venezuela	—	—	37,784	170,635
Total	3,147,248	12,953,057	3,078,922	12,997,940
Lithium metal:³				
Belgium	319	NA	6,788	NA
Brazil	—	NA	48	NA
Colombia	524	NA	—	—
Germany, Federal Republic of	34,500	NA	4,190	NA
Gabon	—	—	39	NA
Israel	349	NA	—	—
Japan	40,699	NA	46,035	NA
Kenya	2	NA	—	NA
Malaysia	61	NA	—	—
Netherlands	64	NA	132	NA
Nigeria	—	—	39	NA
South Africa, Republic of	149	NA	103	NA
Spain	4,936	NA	—	—
Syria	38	NA	—	—

See footnotes at end of table.

TABLE 3—Continued
U.S. EXPORTS OF LITHIUM CHEMICALS, BY COMPOUND AND COUNTRY

Compound and country	1990		1991	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Lithium metal²—Continued				
Taiwan	147	NA	—	—
United Kingdom	29,949	NA	—	—
Total	111,737	NA	57,373	NA

NA Not available.

¹Data may not add to totals shown because of independent rounding.

²Pharmaceutical-grade lithium carbonate.

³According to the Journal of Commerce Port Import/Export Reporting Service and adjusted by the U.S. Bureau of Mines.

Source: Bureau of the Census.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF LITHIUM CHEMICALS

	Compounds			
	1990		1991	
	Quantity (kilograms)	Value ¹	Quantity (kilograms)	Value ¹
Lithium carbonate:				
Canada	—	—	170	\$15,451
Chile	4,196,689	\$8,337,590	3,108,820	7,363,384
Germany, Federal Republic of	20	1,849	200	7,303
India	—	—	—	—
Japan	20	29,008	645	43,126
Singapore	50	5,400	—	—
United Kingdom	56	7,491	—	—
Total²	4,196,834	8,381,338	3,109,834	7,429,264
Lithium hydroxide:				
Canada	—	—	50	3,975
China	—	—	16,422	64,080
Germany, Federal Republic of	130	14,292	200	13,155
Japan	241	2,779	5	15,768
United Kingdom	100	2,994	3,698	31,499
Total	471	20,065	20,375	128,477

¹Customs value.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 5
WORLD LITHIUM ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1991, RATED CAPACITY¹

Country	Capacity
(Metric tons of contained lithium)	
North America:	
United States ²	5,600
Canada	500
Total	6,100
South America:	
Argentina [*]	10
Brazil [*]	290
Chile	2,200
Total[*]	2,500
Europe:[*]	
Portugal	18
U.S.S.R. ³	1,089
Total⁴	1,100
Africa:	
Namibia [*]	30
Zimbabwe	730
Total	760
Asia: China ³	730
Oceania: Australia	1,300
World total⁴	12,000

^{*}Estimated.

¹Includes capacity at operating plants as well as plants on standby basis.

²Figures for the United States include 1,500 metric tons of capacity that has been idle since 1986.

³These estimates denote only an approximate order of magnitude; no basis for more exact estimates is available. Output from China and the U.S.S.R. has never been reported.

⁴Data do not add to total shown because of independent rounding.

TABLE 6
LITHIUM MINERALS AND BRINE: WORLD PRODUCTION, BY
COUNTRY¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991 [*]
Argentina (minerals not specified)	178	119	[*] 104	[*] 120	110
Australia, spodumene	22,279	[*] 30,000	[*] 40,000	[*] 40,000	50,000
Brazil:					
Amblygonite ^o	52	25	[*] 25	[*] 25	25
Petalite	2,946	1,115	[*] 1,200	[*] 1,200	1,200
Spodumene	505	331	[*] 350	[*] 350	350
Canada, spodumene ^{o3}	11,500	14,000	14,000	[*] 12,000	11,500
Chile, carbonate from subsurface brine	6,139	7,332	7,508	[*] 9,081	9,000
China (minerals not specified) ^{o4}	15,000	15,000	15,000	15,000	15,500
Namibia:					
Amblygonite	106	147	131	[*] 54	50
Lepidolite	61	18	41	[*] 80	50
Petalite	749	1,477	1,226	[*] 1,134	1,000
Portugal, lepidolite	9,380	14,109	18,264	[*] 10,614	12,000
U.S.S.R. (minerals not specified) ^{o4}	55,000	55,000	55,000	55,000	50,000
United States, spodumene and subsurface brine	W	W	W	W	W
Zimbabwe (minerals not specified)	14,959	15,073	20,647	[*] 19,053	19,100

^{*}Estimated. ^oRevised. W Withheld to avoid disclosing company proprietary data.

¹Table includes data available through Apr. 4, 1992.

²In addition to the countries listed, other nations may produce small quantities of lithium minerals, but output is not reported, and no valid basis is available for estimating production levels.

³Estimates based on imports by the United States.

⁴These estimates denote only an approximate order of magnitude; no basis for more exact estimates is available. Output by China and the U.S.S.R. has never been reported.

MAGNESIUM AND MAGNESIUM COMPOUNDS

By Deborah A. Kramer

Ms. Kramer is a physical scientist with the Branch of Industrial Minerals. She has covered magnesium and magnesium compounds for 8 years. Domestic survey data were prepared by Lillian M. Wood, statistical assistant; international data tables were prepared by Ron Hatch, international data assistant, and William Zajac, Chief, Section of International Data.

U.S. magnesium production declined for the second year in a row, primarily because of depressed economic conditions and competition from imports from Canada. In a reaction to the increased imports from Canada, one U.S. producer filed an antidumping and countervailing duty suit charging the Canadian producers with material injury to U.S. industry.

The world magnesium industry in 1991 was marked with capacity shutdowns to mitigate the effects of inventory buildup that occurred during the year. Plants in Canada, Norway, the United States, and Yugoslavia announced temporary capacity shutdowns citing reasons such as deteriorating market conditions and availability of less costly material from the former U.S.S.R. One plant in Canada that had opened in 1990 was closed permanently because of technical difficulties. In conjunction with these closures, market prices throughout the world dropped significantly during the year.

U.S. production of magnesium compounds declined for the third year in a row. Seawater and brines were the source materials for 72% of the total production of magnesium compounds. Refractories were the principal end use for most of the magnesia produced, but represented a smaller-than-usual share of total consumption. Caustic-calcined magnesia was used in the agricultural, chemical, construction, and manufacturing industries.

One new magnesia plant opened in Australia during 1991, and expansions in capacity were planned in Canada, India,

and Israel. In addition to new plant construction, many magnesia producers were developing new products to increase the use of magnesia in applications such as environmental uses and flame retardants. Refractories manufacturers continued to upgrade their facilities to produce improved products to satisfy the needs of the iron and steel, nonferrous metals, glass, and cement industries.

DOMESTIC DATA COVERAGE

Data for magnesium metal are collected from two voluntary surveys of U.S. operations. Of the 118 companies canvassed for magnesium consumption data, 96% responded, representing 53% of the primary magnesium consumption shown in tables 4 and 6. Data for the five nonrespondents were estimated based on prior year consumption levels and other factors.

Data for magnesium compounds was collected from one voluntary survey of U.S. operations. Of the 19 operations canvassed, 84% responded, representing 72% of the magnesium compounds shipped and used shown in table 14. Data for the three nonrespondents were estimated based on prior year consumption levels and other factors.

BACKGROUND

Definitions, Grades, and Specifications

Primary magnesium metal contains a minimum of 99.8% magnesium. Magnesium-base alloys are named by the

composition of the two chief alloying elements, each designated by a letter, and the approximate percentage of each alloying element. For example, AZ91 contains about 9% aluminum (A) and 1% zinc (Z), and HK31 contains about 3% thorium (H) and 1% zirconium (K). Other letters used in specifying magnesium alloys are E for rare-earth metals and M for manganese.

Magnesite, or magnesium carbonate ($MgCO_3$), has a theoretical magnesium content of 47.6%. Dolomite is a calcium carbonate-magnesium carbonate mineral ($CaCO_3 \cdot MgCO_3$) that has a theoretical magnesium content of 22%. Brucite, magnesium hydroxide [$Mg(OH)_2$], contains up to 69% magnesium, and olivine ($Mg_2Fe_2SiO_4$) contains up to 19% magnesium. Of these minerals, magnesite and dolomite are the largest sources of magnesium and magnesium compounds.

Seawater, brines, and bitterns represent vast sources of magnesium and magnesium compounds. In the United States, more than 60% of the magnesium compounds produced annually is recovered from seawater and brines, and 80% of the magnesium metal production capacity uses seawater or brines as a raw material.

Various magnesia products are made by calcining magnesium carbonate or magnesium hydroxide at different temperatures. Caustic-calcined magnesia, which is readily reactive with water, is calcined at temperatures up to 890° C. Dead-burned magnesia, also called refractory or sintered magnesia, is

calcined at temperatures up to 1,450° C and is unreactive with water. Fused magnesia is produced at temperatures greater than 3,000° C. Magnesia produced from magnesite is generally called natural magnesia, and magnesia produced from seawater or brines is called synthetic magnesia.

Standards for magnesia, including chemical composition, bulk density, and particle size, generally are set by the consumer for a specific application. Refractory magnesia composition depends on the area of the furnace in which the material is to be used. Magnesia produced from magnesite can contain between 88% and 98% magnesia, with varying quantities of silica, iron, calcium, and alumina impurities. Synthetic magnesia normally is purer than natural magnesia, containing between 92% and 99.5% magnesia, with smaller quantities of the same impurities found in natural magnesia. Most fused magnesia contains greater than 94% magnesia.

Products for Trade and Industry

The principal use for magnesium metal, averaging greater than 50% of U.S. consumption annually, is as an alloying addition to aluminum. Magnesium improves the hardness and corrosion resistance of pure aluminum. Aluminum-magnesium alloys are used in a variety of applications, including automobiles, trucks, aircraft, appliances, and home siding. Two-piece beverage cans, containing about 2% magnesium, are the largest single use for these aluminum-magnesium alloys.

Magnesium and its alloys are used as structural components on automobiles, trucks, aircraft, computers, and power tools. Many of these applications use magnesium because of its light weight and ease of machinability. Magnesium is used in the iron and steel industry for external hot-metal desulfurization and in the production of nodular iron. Production of the nonferrous metals, beryllium, hafnium, titanium, uranium, and zirconium, involves the use of magnesium as a reducing agent. Anodes of magnesium are used for cathodic

protection of underground pipe and water tanks. Small quantities of magnesium are used as a catalyst in producing organic compounds, as photoengraving plates, and in alloys other than aluminum.

Refractory magnesia represents the largest use of magnesium in compounds. Refractory magnesia is manufactured into bricks and other shapes principally for linings in furnaces and auxiliary equipment used to produce iron and steel. Magnesia-base refractories also are used in furnaces in the cement, glass, and nonferrous metals industries.

Caustic-calcined magnesia is used in a variety of applications in the agricultural, chemical, construction, and manufacturing industries. Caustic-calcined magnesia is an important component of animal feed and fertilizer, providing essential nutrients for livestock and plant growth. In construction, caustic-calcined magnesia is used in special cements for industrial flooring and in lightweight insulating wallboard. In the chemical industry, it is used as a starting point for the manufacture of other magnesium salts. Special grades of caustic-calcined magnesia are used for pharmaceuticals, including antacids, toothpaste, milk of magnesia, and cosmetics. Magnesia is used to remove sulfur from flue gases and boiler fuels and is used for acid neutralization in process wastewater and in lubricating oils. Caustic-calcined magnesia is also important in manufacturing paper, rayon, and rubber.¹

Other magnesium compounds are used in place of, or in addition to, caustic-calcined magnesia in many of the above applications. Magnesium hydroxide is used in the pulp and paper industry; magnesium sulfate is used for pharmaceuticals, animal feed, and fertilizers; and magnesium carbonate is used in the chemical, pharmaceutical, and rubber industries. Fused magnesia is used primarily for electrical insulation.

The principal use for olivine is as a foundry sand used in casting iron and steel components and some nonferrous metals. Olivine is used in smaller quantities for refractories, slag control in blast furnaces, and soil conditioning. In

Europe, olivine is used instead of silica sand for blasting debris from bridges and buildings and in incinerators.²

Industry Structure

U.S. producers of magnesium and magnesium compounds are shown in tables 1 and 2. Olivine is produced by two companies in the United States—Applied Industrial Minerals Corp. (AIMCOR) and Olivine Corp. AIMCOR operates two mines in North Carolina and Washington and processing plants in Indiana, North Carolina, and Washington, and Olivine operates one mine and one processing plant in Washington.

Electrolytic plants in Canada, Norway, the U.S.S.R., and the United States represent 85% of the world magnesium metal production capacity. Smaller thermal plants are in Brazil, Canada, China, France, India, Italy, Japan, and Yugoslavia.

The largest magnesite production facilities in the world are in China, North Korea, and the U.S.S.R. Together, these three countries account for 53% of the world magnesite production capacity. Japan and the United States account for 59% of the world's magnesium compounds production capacity from seawater or brines. Fused magnesia is produced in Canada, France, Israel, Japan, the United Kingdom, and the United States.

Norway is the world's principal producer of olivine, and in addition to supplying its domestic needs, Norway is a major world supplier of olivine. Countries with smaller output are Austria, Italy, Japan, Mexico, Spain, Sweden, and the United States. (See tables 1 and 2.)

Geology

Magnesium is the eighth most abundant element and constitutes about 2% of the Earth's crust. It is the third most plentiful element dissolved in seawater, with a concentration averaging 0.13%. Although many minerals contain magnesium, magnesite, dolomite, brucite, and olivine are the only minerals from

which magnesium compounds are recovered commercially.

Dolomite is a sedimentary rock commonly interbedded with limestone, which extends over large areas of the United States. Most dolomite occurrences are likely the result of replacement of calcium by magnesium in preexisting limestone beds. Magnesite primarily is found in four types of deposits—sedimentary beds, alterations of serpentine, vein fillings, and replacements of limestone and dolomite. Brucite is found in crystalline limestone and as a decomposition product of magnesium silicates associated with serpentine, dolomite, magnesite, and chromite. Olivine generally occurs as granular masses or disseminated grains or crystals and is a common constituent of basic igneous rocks such as basalt and gabbro. Dunite is an olivine-rich rock.³

Technology

Processing—Metal.—Two thermal processes currently are in use to recover magnesium metal from dolomite—the Pidgeon process and the Magnetherm process. Both use the same basic chemistry, but the Pidgeon process uses an external heat source, and the Magnetherm process uses heat generated by the electrical resistance of the reactants. In the Pidgeon process, dolomite and ferrosilicon are formed into briquettes and heated in a retort under a vacuum. Magnesium oxide in the dolomite reacts with the ferrosilicon to produce magnesium vapor, which is cooled and condensed in a separate section of the retort. Plants in Canada, Italy, and Japan use this process to recover magnesium.

In the Magnetherm process, calcined dolomite, ferrosilicon, and alumina are heated under a vacuum. Alumina reduces the melting point of the slag produced by the dolomite-ferrosilicon reaction to make resistance heating practical. Magnesium vapor is cooled and condensed in a condensing chamber. The Magnetherm process is used in plants in Brazil, France, Japan, the United States, and Yugoslavia.

Electrolytic recovery of magnesium requires a magnesium chloride feedstock that normally is prepared from seawater or brines. Two types of magnesium chloride can be made—hydrous and anhydrous. In the preparation of hydrous magnesium chloride, used by Dow Chemical Co., magnesium hydroxide is precipitated from seawater by the addition of dolomitic limestone. Adding hydrochloric acid to the magnesium hydroxide produces a neutralized magnesium chloride solution. This solution is dehydrated until it contains about 25% water and then is fed directly to electrolytic cells.

Magnesium Corp. of America (MagCorp) and Norsk Hydro A/S of Norway use an anhydrous magnesium chloride feed for their electrolytic cells. MagCorp uses solar evaporation initially to concentrate magnesium chloride brines from the Great Salt Lake. After adding calcium chloride to precipitate sulfate impurities and removing boron by solvent extraction, the brine is concentrated further and dehydrated in a spray dryer. The resulting powder is purified, concentrated, prilled, and dehydrated to produce anhydrous magnesium chloride.⁴ Norsk Hydro starts with concentrated magnesium chloride brine. The brine is purified, concentrated, prilled, and dehydrated to produce anhydrous magnesium chloride.

Electrolytic cells used to recover magnesium from either hydrous or anhydrous magnesium chloride differ from company to company, and most information about cell design and operating conditions usually are not disclosed. Essentially, magnesium chloride fed to an electrolytic cell is broken down into magnesium metal and chlorine gas by direct current at 700° C. Magnesium is removed from the cell and cast into ingots, and the chlorine gas is recycled or sold.

Magnesium International Corp. developed a one-step process for producing anhydrous magnesium chloride that was demonstrated at Magnesium Co. of Canada Ltd.'s (MagCan) new plant that opened in 1990 and closed in 1991. Reacting magnesite with chlorine gas in

the presence of carbon monoxide in a packed-bed reactor at 900° C produces magnesium chloride and carbon dioxide. Liquid magnesium chloride collects at the bottom of the reactor and is tapped periodically for transfer to electrolytic cells.⁵

Processing—Nonmetal.—Preparing either caustic-calcined or dead-burned magnesia from magnesite involves crushing the magnesite to various sizes, depending on the type of material to be produced. After crushing, magnesite is beneficiated; the degree of beneficiation depends on the quality of the ore and its ultimate end use. Lower quality ore often requires heavy-media separation, magnetic separation, and flotation to remove impurities. High-quality ore may require only screening and hand sorting to produce a material of acceptable quality. Caustic-calcined magnesia is produced in shaft kilns, multiple-hearth furnaces, or rotary kilns. Dead-burned magnesia is produced in rotary or shaft kilns.

In producing synthetic magnesia, seawater or brines are treated either with a small quantity of lime or sulfuric acid to remove dissolved carbon dioxide. Then calcium hydroxide, in the form of lime or dolime, is added to precipitate the dissolved magnesium as magnesium hydroxide. The resulting slurry is thickened and vacuum-filtered to yield a filter cake containing about 50% magnesium hydroxide. The filter cake can be directly calcined to produce caustic-calcined or dead-burned magnesia, or it can be calcined and pelletized before dead-burning to give specific size and density characteristics.

Fused magnesia is produced by fusion of high-grade magnesite or caustic-calcined synthetic magnesia in an electric arc furnace. After fusion, the material is crushed, inspected to remove any unfused magnesia, and crushed further in a ball mill.

Recycling.—Magnesium scrap is in forms similar to those of other nonferrous metals. New scrap comes in forms such as castings, drippings, drosses, gates,

runners, and turnings. Old scrap primarily comes from old aircraft parts and discarded consumer products, such as lawnmower decks, chainsaw housings, and hand tools. The diecasting industry traditionally is the largest source of scrap magnesium.

Sorted scrap is charged into a steel crucible, which is heated to 675° C. As the scrap at the bottom begins to melt, more scrap is added. The liquid magnesium on the bottom is covered with a flux to inhibit surface burning. After any alloying elements are added and melting is complete, molten magnesium is transferred to ingot molds by either hand ladling, pumping, or tilt pouring.⁶

Economic Factors

Costs to produce magnesium metal vary greatly, depending upon the feed material and the process used. Operating costs for magnesium production range from \$309 to \$2,283 per metric ton, with energy costs as the largest component of the total operating cost. Total production costs from seawater sources were lower than from brines or dolomite sources. Magnesium compound operating costs also vary depending upon source material and processing techniques. Operating costs range from \$24 to \$425 per ton for magnesium compound production, with seawater as the most costly source. Energy costs also represent the largest component of total operating costs.⁷

Tariffs for magnesium and magnesium compounds are shown in table 3. The depletion allowance for magnesium chloride from domestic or foreign sources is 5%. Magnesium carbonate and dolomite have depletion allowances of 14% from domestic and foreign ores. Depletion allowances for other ores are brucite, 10% (domestic and foreign); and olivine, 22% domestic and 14% foreign. (See table 3.)

ANNUAL REVIEW

Magnesium

Legislation and Government Programs.—On September 5, MagCorp initiated an antidumping and countervailing duty investigation into imports of magnesium from Canada and Norway. In its petition filed with the International Trade Commission (ITC), MagCorp claimed that imports of pure and alloy magnesium were being sold in the United States for less-than-fair value. MagCorp also claimed that these imports threaten material injury to the U.S. magnesium producers.⁸ On September 25, ITC dismissed the countervailing duty investigation concerning imports of primary magnesium from Norway.⁹

On December 2, the International Trade Administration (ITA) announced a preliminary determination that magnesium imports from Canada were subject to a countervailing duty of 32.85% ad valorem. This determination applies only to Norsk Hydro; Timminco Ltd.'s countervailing margins were assessed at 0.04%, less than the amount for which duties are collected. ITA cited five programs that benefited Norsk Hydro—preferential electric rates, grants from the Quebec Industrial Development Corp., exemptions from water bills, Institute of Magnesium Technology research, and the Canadian-Quebec Subsidy Agreement.¹⁰ Final countervailing duties and preliminary antidumping duties were scheduled to be announced in 1992.

On May 20, the Environmental Protection Agency made a final determination that none of the 20 waste streams excluded from the Resource Conservation and Recovery Act (RCRA) under the Bevill amendment will be regulated as hazardous. Included in this determination is wastewater from magnesium processing generated at MagCorp's plant in Rowley, UT. The 20 waste streams may be regulated under a special subtitle D of RCRA being developed for nonhazardous mining extraction and beneficiation wastes.¹¹

Production.—U.S. primary magnesium producers operated at about 73% of their rated capacity in 1991, and total production dropped by about 6% from that of 1990.

Northwest Alloys Inc., a wholly owned subsidiary of the Aluminum Co. of America (Alcoa), announced in late December that it would reduce the operating rate at its Addy, WA, magnesium production plant by 50% by March 31, 1992. About one-half of the plant's work force of 500 was expected to be laid off. Northwest Alloys had been supplying outside contracts in addition to Alcoa's internal needs, but after the shutdown, outside contracts will not be renewed after they expire. The plant, which uses the Magnetherm process, has nine furnaces, but has been running only seven or eight for most of the year. The shutdown will reduce the number of active furnaces to four or five. (See table 4.)

Consumption and Uses.—U.S. automakers continued to replace some aluminum and steel components with magnesium. General Motors Corp. planned to incorporate 6.8 kilograms of magnesium parts into its V-8 engines for limited use in its Cadillac models beginning in mid-1992. Ford Motor Co. approved 1.1-kilogram magnesium seat supports for its 1994 model Aerostar minivans. Ford also announced that it would use magnesium steering columns in the 1992 models of its light-duty trucks. By 1993, Ford estimates that the steering columns, which are already incorporated in some of its passenger cars, will consume about 6,700 tons of magnesium annually. Suppliers for the steering columns will be Diemakers Inc., Monroe City, MO, and the Contech Div. of SPX Corp., Kalamazoo, MI.

Chrysler Corp. planned to use almost 2.7 kilograms of magnesium in engine components in its low-volume Viper sports cars, due out in 1992. Chrysler also expected to use 1.4-kilogram magnesium steering column brackets in its 1993 models of a new midsize car. In addition, Chrysler announced that it

would incorporate 2 kilograms of magnesium accessory drive brackets in its 1993 Jeep sports utility wagons.

Diemakers was chosen as the supplier for magnesium valve covers for the 1994 models of Chrysler's T-300 truck V-10 engines and its 1992 Dodge Viper 10-cylinder engines. The truck valve covers were expected to require more than 70 tons of magnesium annually, and the Viper valve covers were expected to use more than 11 tons annually. As a result, Diemakers broke ground for an additional 3,600-ton-per-year expansion that would double the company's total diecasting capacity.

Toyota Motor Corp. reportedly began purchasing magnesium cam covers from U.S.-based Tennessee Diecasting Div. of Harvard Industries Inc. for some of its in-line 6-cylinder engines. Each cam cover uses about 1.8 kilograms of magnesium.

As a result of the increased interest in magnesium automotive components, Spectrulite Consortium Inc. and Latrobe Industries Inc. formed a joint venture to produce magnesium castings primarily for this market. Initial plans were to convert existing aluminum casting equipment at Latrobe's plant in Pennsylvania to magnesium casting. Latrobe Spectrulite scheduled its first production for the second quarter of 1991 and planned to install additional casting equipment as sales volume requires. (See tables 5 and 6.)

Stocks.—Consumer stocks of primary magnesium ingot decreased to 4,876 tons at yearend 1991 from 5,428 tons at yearend 1990. Consumer stocks of magnesium alloy ingot also decreased to 739 tons at yearend 1991 from 879 tons at yearend 1990. Producers' stocks of primary magnesium were 21,294 tons at yearend 1991, a 9% increase from 1990 yearend stocks of 19,535 tons. (See table 7.)

Markets and Prices.—At the beginning of the year, MagCorp announced that it lowered its price for primary magnesium by 20 cents to \$1.43 per pound in order

to match Dow's price, which had been decreased to \$1.43 per pound in December 1990. Although both companies maintained these price quotes throughout the rest of 1991, press sources reported that actual selling prices for primary magnesium were about \$1.10 to \$1.25 per pound by yearend.

At the end of January, Dow announced that it would reduce its prices for diecasting alloy AZ91D from \$1.43 to \$1.34 per pound. As an incentive for automobile manufacturers to use magnesium, alloy prices traditionally have been lower than primary magnesium prices. By reducing the quoted price, Dow reinforced this tradition. Reductions in both primary metal and diecasting alloy prices were attributed to increases in inventories and surplus capacity.

Foreign Trade.—Exports of magnesium increased by 6% from those of 1990. The Netherlands (28%), Japan (24%), and Canada (15%) were the primary destinations for U.S. exports. The United States continued as a net exporter of magnesium.

For the second year in a row, Canada was the principal source of magnesium imports, accounting for 89% of the total in 1991. Total imports were 19% greater than those in 1990; most of this increase was the result of increased imports of primary metal from Canada. (See tables 8 and 9.)

World Review.—World production of primary magnesium dropped by about 4% in 1991, with most of the decline in Europe and the United States. According to the International Magnesium Association, world inventories were 55,100 tons at yearend 1991, which was a 26% increase from inventories at yearend 1990.

By the second quarter of 1991, Dow and Norsk Hydro increased price quotes for primary magnesium marketed in Europe by 5%, but neither company would say how much the increase was or what the new prices were. According to the companies, the new price quotes more accurately reflected supply-demand

conditions. Press sources indicated that magnesium was selling at approximately \$1.10 to \$1.20 per pound in Europe.

By yearend, however, significant quantities of magnesium reportedly were entering the European market from the U.S.S.R., which led to an oversupply situation, and reports of prices for this material were about 80 cents per pound. To correct what the company felt was erroneously low free market price quotes stemming from the Soviet material, Norsk Hydro announced that they would establish a European producer price beginning in 1992. Norsk Hydro planned to report this price on a quarterly basis and stated that the new price quote would reflect actual transaction prices. In December, Norsk Hydro announced that the first quarter 1992 price would be 3.85 Deutchemarks per kilogram, equivalent to about \$1.09 per pound. (See table 10.)

Australia.—Queensland Metals Corp. (QMC) reportedly accelerated the development of its planned 60,000-ton-per-year magnesium production plant in Australia. Design studies for a pilot plant were scheduled to be completed by yearend, and research continued on producing high-purity magnesium chloride from QMC's magnesite deposit to feed the proposed plant. QMC's accelerated development of the project was prompted by the projected increase in the use of magnesium in automotive applications. The Australian Government announced that it would help fund a research project to construct a 1,600-ton-per-year pilot plant to produce magnesium from QMC's magnesite deposit. The planned completion date for the pilot plant is 1994.

Brazil.—In July, Cia. Brasileira de Magnesio (Brasmag) filed a petition with the Brazilian Economy Ministry Department claiming that U.S. and Canadian magnesium producers dumped magnesium and magnesium alloys in Brazil. According to Brasmag, Norsk Hydro in particular was able to sell its magnesium at a low cost because of Government subsidies. Brasmag reportedly reduced its annual production

rate from 12,000 tons to 8,000 tons because of the alleged dumping. Brasmag also indicated that the dumping occurred when the Brazilian Government decided to open its economy by reducing import duties. According to Norsk Hydro, however, its sales to Brazil were small; the company exported 57 tons of magnesium to Brazil in 1990 and planned to increase that to 200 to 300 tons in 1991. Decisions on the antidumping charges were expected to be completed in 1992.

Canada.—In April, Alberta Natural Gas Co. Ltd. (ANG) announced that it would no longer fund the 12,500-ton-per-year primary magnesium plant operated by MagCan. ANG, the project's primary financial backer, cited high operating costs and high interest rates as factors in its decision. MagCan's plant in Alberta was closed at the end of April. The plant had not operated at full capacity since its startup in early 1990 because of technical problems at the facility. At yearend, the Province of Alberta was seeking a buyer for the closed plant; the Province had issued loan guarantees for the plant.

Timminco reportedly began a reorganization of its metals division in April, which included a reduction in production at its Haley, Ontario, primary magnesium plant. The reorganization was expected to result in adjusted inventories and production levels in line with current demand.

Norsk Hydro planned to cut back production at its Becancour, Quebec, primary magnesium plant by 40% to about 20,000 tons per year, beginning in November. Although the rated annual capacity of the plant was 45,000 tons, the plant reportedly had been operating at a rate of 35,000 tons per year. With the reduction in capacity at Becancour, coupled with an earlier cutback at the company's Porsgrunn, Norway, plant, Norsk Hydro expected the company's total production in 1992 to drop by 25,000 to 35,000 tons from 1991 levels.

Development of the Magnola project in Quebec suffered a setback because of the bankruptcy of the Lavalin group, owner of one of the joint-venture partners.

Although Lavalin has been purchased, Noranda, the second joint-venture partner, did not know what the corporation that purchased 52% of Lavalin intends to do with the Magnola project. Any startup of a planned 50,000-ton-per-year plant designed to recover magnesium from asbestos tailings has been delayed until 1997. A third joint-venture partner is being sought for the project, and the next stage, which involves an engineering and feasibility study, has been delayed until the end of 1992.

Hydro Magnesium announced that it signed an agreement with Meridian Technologies of Canada to develop magnesium wheels for the North American automobile industry. The development programs will consist of two stages. First, the market prospects will be analyzed, and a process to produce high-pressure magnesium wheel diecastings will be developed. A decision on the second stage, construction of a wheel plant, was expected to be made early in 1992.

Japan.—Magnesium demand exceeded 27,000 tons in 1990, according to the Japan Light Metals Association, which was an alltime record. Aluminum alloys, primarily for use in beverage cans and in construction, accounted for about 74% of Japan's magnesium demand. Castings accounted for about 5%, nodular cast iron production accounted for 11%, and the remaining 10% of demand was consumed for cathodic protection and other uses. Demand for magnesium in 1991 was projected to be 30,000 tons, with aluminum alloying continuing as the largest end-use sector.¹²

Norway.—Norsk Hydro announced that it would cut back production at its Porsgrunn plant to 35,000 tons per year by closing one of the plant's two production lines. The plant reportedly was operating at an annualized rate of 45,000 tons until the shutdown in the autumn. During the closure, Norsk Hydro planned to modernize the facilities to improve flexibility. The shutdown was scheduled to last for 2 years.

Beginning in 1992, Norsk Hydro will need to find a new raw material source for magnesium production. Kali und Salz GmbH, a German potash producer, was supplying the Porsgrunn facility with byproduct magnesium chloride brines from its Salzdetfurth facility. Kali und Salz planned to close this facility during 1991 and would be able to supply Norsk Hydro through yearend 1991 from stocks. Billiton Refractories BV of the Netherlands was cited as a potential supplier of magnesium chloride raw materials from its solution mining operation in Veendam.¹³

Yugoslavia.—In February, Magnohrom reportedly cut back production at its 7,000-ton-per-year primary magnesium plant in Bela Stena by 15% to 20%, citing deteriorating market conditions and availability of less costly material from the U.S.S.R. During the cutback, which may extend into 1992, Magnohrom planned to overhaul production equipment in order to reduce production costs. (See tables 11 and 12.)

Magnesium Compounds

Production.—Production of caustic-calcined magnesia increased significantly in 1991 at the expense of dead-burned magnesia production, which declined by almost the same quantity. Seawater and brines were the source material for about 72% of the total U.S. production of magnesium compounds. U.S. production of olivine in 1991 declined by 7% from that of 1990, but the average value of production increased by 30%. (See table 13.)

Consumption and Uses.—Dead-burned magnesia refractories for use in metal, cement, and glass production furnaces continued to be the primary application for magnesium compounds in the United States. In 1991, agricultural applications (animal feed and fertilizer) were the dominant use for caustic-calcined magnesia, accounting for 26% of U.S. shipments. Chemical processing was the next largest segment, with 22% of total

shipments. The following categories, with the individual components in parentheses in declining order, were the other end-use sectors for caustic-calcined magnesia: Metallurgical (refractories, water treatment, electrical, foundry, and stack-gas scrubbing), 21%; manufacturing (rayon, fuel additives, rubber, and pulp and paper), 17%; construction (oxychloride and oxysulfate cements, general construction, and insulation), 6%; pharmaceuticals and nutrition (medicinal and pharmaceutical, sugar, and candy), 3%; and unspecified uses, 5%.

Magnesium carbonate was used principally in medicines and pharmaceuticals, with additional applications in chemical processing and fertilizers. Magnesium hydroxide was used mainly in the pulp and paper and chemical industries, with smaller usage in water treatment and medicines. Magnesium sulfate was used mostly in pharmaceuticals and animal feed. Other applications for magnesium sulfate included chemical processing, insulation, and oxysulfate cements. Magnesium chloride was used in chemical processing and in oxychloride cements. Magnesium chloride brines were used for road dust control and chemical processing.

Foundry uses continued to be the largest application for olivine in the United States, accounting for 66% of consumption of domestically produced material. Refractory applications accounted for 16%, sand blasting and other abrasive applications accounted for 11%, and slag control accounted for the remaining 7% of U.S. olivine consumption.

Martin Marietta Magnesia Specialties Div. announced the development of a new product for water treatment applications. The new product, called FlowMag, was designed to remove heavy metals and neutralize acids from industrial wastewater processing streams. The new product reportedly produces less than 30% of the sludge volume normally produced when the wastewater is treated in a clarifier system. Disposal costs, therefore, were lower, and the company claimed that FlowMag was 40% to 100% more efficient on a weight basis.

In a review article on flame retardants, the properties of magnesium hydroxide were discussed. Magnesium hydroxide has a flame retardant effect by releasing its water of hydration to delay combustion, and when combustion does occur, the combustion products are nontoxic. Magnesium hydroxide competes with aluminum trihydrate in flame retardant applications. It is slightly less effective, but it also is less costly. The main application for magnesium hydroxide is in polymers such as polypropylene and nylon, which have to be processed at high temperatures.¹⁴

The glass industry used a variety of magnesia-base refractories in its production furnaces; magnesia, magnesia-chrome, and magnesia-spinel bricks were the most commonly used. Magnesia-chrome bricks were becoming less frequently installed in newer furnaces because of environmental concerns about the hexavalent chrome ion. Hexavalent chrome is considered carcinogenic and is water soluble. Problems arise when the refractories are removed from the furnace and discarded. New furnaces tended to install magnesium-aluminum-spinel, high-alumina, and fused-cast refractories to alleviate the environmental risks.¹⁵ (See table 14.)

Markets and Prices.—Yearend prices for magnesium compounds, as quoted in the Chemical Marketing Reporter, remained the same as those at yearend 1990. Beginning in 1991, the U.S. Bureau of Mines began including prices for dead-burned and synthetic magnesia in table 15. (See table 15.)

Foreign Trade.—Olivine trade data were not reported separately by the Bureau of the Census. The Journal of Commerce Port Import/Export Reporting Service (PIERS) provided some information on U.S. trade in olivine; this source, however, reports only those materials that are transported by ship. According to PIERS, 2,424 tons of olivine was exported in 1991. Peru, 44%, and Chile, 40%, were the primary recipients. Imports of olivine, all from

Norway, totaled 93,755 tons. (See tables 16, 17, 18, and 19.)

World Review.—Australia.—Production at QMC's open pit magnesite mine at Kunwarara, Queensland, began in early April. By June, the first ore from the mine was run through the preconcentration and beneficiation plants in Parkhurst. During the first year of production, QMC expected to produce 67,000 tons of dead-burned magnesia and 12,000 tons of fused magnesia. Total annual production at the plant was expected to reach 150,000 tons of dead-burned magnesia and 25,000 tons of fused magnesia by 1995.

In addition to dead-burned and fused magnesia, QMC was developing other magnesia products through joint-venture operations. QMC was working with CSIRO on three projects, called Environmag, Cemag, and Flamemag. The Environmag project was investigating the market potential and technical requirements for magnesia and magnesium hydroxide in environmental applications. Cemag was a research and development project for the production of magnesia-base cements. Flamemag was also a research and development project to develop low-cost, high-purity magnesia and magnesium hydroxide for use as flame retardants.¹⁶

Austria.—Radex Heraclith AG announced that it purchased a majority stake in Austria's other magnesite producer, Veitscher Magnesitwerke AG in April. Radex planned to combine its refractories operations with the newly purchased shares of Veitscher Magnesitwerke into a holding company, Osterreichische Magnesit AG. Radex operated a magnesite mine and 120,000-ton-per-year magnesia plant, and Veitscher Magnesitwerke operated a mine and 375,000-ton-per-year magnesia plant.

Canada.—By early 1991, Baymag's fused magnesia plant in Exshaw, Alberta, reportedly was operating at 20% more than its rated annual capacity of 14,000 tons. In response to the demand for fused magnesia, the plant was scheduled

to undergo an expansion to double capacity by the addition of two furnaces.

Czechoslovakia.—The Government-owned magnesite mining operation, Slovenske Magnezitove Zaovdy (SMZ), announced plans to decrease magnesite extraction by 25% by the year 2000. Adverse ecological effects of the mining operations were cited as the reason for the decrease in production. Instead of increasing production to generate more revenue, SMZ planned to focus on improving the quality of its products.

Greece.—Grecian Magnesite S.A. and Lafarge Refractaires Monolithiques of France reportedly formed a joint venture to produce basic monolithic refractories at a new plant in Greece. The joint-venture company, Ellamag Monolithic Refractories S.A., will be owned 51% by Lafarge and 49% by Grecian Magnesite. Grecian Magnesite will provide the raw materials from its nearby mines, and Lafarge will provide its expertise in refractories. Ellamag's initial capacity was expected to be 18,000 tons per year, and production was scheduled to begin in the spring of 1992.

India.—In an article reviewing the country's industrial minerals, changes in India's magnesite industry were highlighted. More than 80% of India's magnesite reserves were high in calcium oxide and iron oxide, and consequently were not suitable as refractory materials for India's iron and steel industry. Magnesite producers were considering further beneficiation of the magnesite or producing magnesia from seawater to satisfy the iron and steel industry's needs. Demand for dead-burned magnesia in the iron and steel industry is declining with the decrease in the use of open-hearth furnaces in steelmaking. Also affecting India's magnesite industry is the policy that prohibits exports of Indian magnesite and allows imports of dead-burned magnesia with less than 6% silica content. Refractories manufacturers are allowed to import dead-burned magnesia at concessional duties on the grounds that domestically produced material is

unsuitable for their needs. Consequently, India's magnesite producers were facing competition from imported material from Brazil, China, North Korea, and Turkey.¹⁷

Tamilnadu Magnesite Ltd. and Khaitan Supermag Ltd. reportedly formed a joint venture to construct a 30,000-ton-per-year high-quality, dead-burned magnesia plant. The joint-venture partnership was called India Magnesia Products Ltd., and initial production was expected to begin in the first quarter of 1993.

Israel.—Dead Sea Periclase Ltd. and Japan's Tateho Chemical Industries Co. Ltd. reportedly formed a partnership to produce fused magnesia in Israel. The new company, called Tateho Dead Sea Fused Magnesia Co., was expected to begin construction of a \$28 million, 13,000-ton-per-year plant at Dead Sea Periclase's existing location in Mishor Rotem in early 1992. Initial product shipments were scheduled to begin at the end of 1993. Tateho Chemical operates fused magnesia plants in Japan and the United States, and Dead Sea Periclase operates a synthetic magnesia plant in Israel. (See tables 20 and 21.)

OUTLOOK

The International Magnesium Association's annual forecast of world magnesium supply and demand for 1991 estimated an annual average growth rate of 3.0% in magnesium consumption from 1990 to 1996. Most of the growth was expected to occur in diecasting, wrought products, and desulfurization applications. In diecasting uses, Japan, North American, and Western European automotive industries were expected to be the largest growth areas. Wrought products, traditionally an area of stable consumption, was the second largest expected growth application. Magnesium's success in automotive applications was expected to translate into wrought product applications in Western Europe and North America. In desulfurization, expected growth in Latin American use of magnesium was responsible for the overall increase in

world demand. The International Magnesium Association also projected capacity utilization rates for the same period. World capacity (not including that of the U.S.S.R. and China) is expected to increase by about 10% from 1991 to 1996, and capacity utilization was expected to be 89% by 1996, compared with 84% in 1991.

Production and demand for magnesium compounds in the United States was expected to remain relatively stable over the new few years, but the proportion of magnesia used as refractories was expected to decrease. As refractories producers improve the quality of their products, furnace linings will not need to be replaced as frequently, thus lowering the demand for magnesia in refractory applications. But other magnesium compounds were gaining applications in new industries, particularly environmentally related applications. The increase in demand for other magnesium compounds, coupled with the decline in refractories demand, was expected to lead to a stagnant demand for magnesia in the United States.

Recent political changes in the former U.S.S.R. may have a significant effect on the supplies of both magnesium metal and magnesite. Normally, most of the magnesium produced in the U.S.S.R. was used in the production of titanium for defense applications. With the shift of emphasis away from defense applications and the country's need for hard currency, much of this magnesium may appear on the world market at greatly reduced prices; this has already occurred in Europe in 1991. In the United States, high tariff rates for countries with non-most-favored-nation status have minimized the effects of Soviet material, but if the independent States are given most-favored-nation status, material imported from the former U.S.S.R. may have a significant impact on U.S. supply of magnesium metal.

For magnesite, the U.S.S.R. was one of the world's largest producers. But non-most-favored-nation tariff rates also affect the importation of caustic-calcined and dead-burned magnesia into the United States. Changes in tariff rates also may

affect the U.S. supply of magnesia, although purity considerations in the products may limit their usefulness in domestic applications. (See table 22.)

¹Industrial Minerals (London). Caustic Magnesia—Industry Follows a Declining Herd. No. 223, Feb. 1987, pp. 43-48.

²Griffiths, J. Olivine—Volume the Key to Success. Ind. Miner. (London), No. 256, Jan. 1989, pp. 25-35.

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TABLE 1
U.S. MAGNESIUM METAL PRODUCERS, BY LOCATION, RAW MATERIAL, AND PRODUCTION CAPACITY IN 1991

Company	Plant location	Raw material	Annual capacity (metric tons)
The Dow Chemical Co.	Freeport, TX	Seawater	109,000
Magnesium Corp. of America	Rowley, UT	Lake brines	35,000
Northwest Alloys Inc.	Addy, WA	Dolomite	35,000
Total			179,000

TABLE 2
U.S. MAGNESIUM COMPOUND PRODUCERS, BY RAW MATERIAL SOURCE, LOCATION, AND PRODUCTION CAPACITY IN 1991

Raw material source and producing company	Location	Capacity (metric tons of MgO equivalent)
Magnesite: Premier Services Inc.	Gabbs, NV	100,000
Lake brines:		
Great Salt Lake Minerals & Chemicals Corp.	Ogden, UT	90,000
Reilly Industries Inc.	Wendover, UT	45,000
Well brines:		
The Dow Chemical Co.	Ludington, MI	200,000
Martin Marietta Chemicals	Manistee, MI	275,000
Morton Chemical Co.	do.	10,000
Seawater:		
Barcroft Co.	Lewes, DE	5,000
The Dow Chemical Co.	Freeport, TX	20,000
Marine Magnesium Co.	South San Francisco, CA	15,000
National Refractories & Minerals Corp.	Moss Landing, CA	165,000
Premier Services Inc.	Port St. Joe, FL	50,000
Total		975,000

TABLE 3
U.S. IMPORT DUTIES

Item	HTS No.	Most favored nation (MFN)	Non-MFN
		Jan. 1, 1991	Jan. 1, 1991
Magnesium:			
Unwrought magnesium	8104.11.0000	8.0% ad valorem	100% ad valorem.
Unwrought magnesium alloys	8104.19.0000	6.5% ad valorem	60.5% ad valorem.
Magnesium waste and scrap	8104.20.0000	Free	Free.
Wrought magnesium	8104.90.0000	14.8 cents per kilogram on Mg content + 3.5% ad valorem	88 cents per kilogram on Mg content + 20.0% ad valorem.
Magnesium compounds:			
Crude magnesite	2519.10.0000	Free	\$10.33 per ton.
Dead-burned and fused magnesia	2519.90.1000	0.4 cent per kilogram	1.7 cents per kilogram.
Caustic-calcined magnesia	2519.90.2000	\$2.07 per ton	\$20.70 per ton.
Other magnesia	2519.90.5000	Free	15.4 cents per kilogram.
Calcined dolomite	2518.20.0000	6% ad valorem	30% ad valorem.
Kieserite, natural	2530.20.1000	Free	Free.
Epsom salts, natural	2530.20.2000	3.7% ad valorem	20% ad valorem.
Magnesium hydroxide and peroxide	2816.10.0000	3.1% ad valorem	25% ad valorem.
Magnesium chloride	2827.31.0000	1.5% ad valorem	5% ad valorem.
Magnesium sulfate	2833.21.0000	3.7% ad valorem	20% ad valorem.

TABLE 4
SALIENT MAGNESIUM STATISTICS

(Metric tons unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Production:					
Primary magnesium	124,396	141,983	152,066	139,333	131,288
Secondary magnesium	45,164	50,207	51,200	54,529	52,913
Exports	44,182	49,802	56,631	51,834	55,160
Imports for consumption	10,851	14,407	12,289	26,755	31,863
Consumption, primary	94,620	100,793	105,226	96,108	91,872
Price per pound	\$1.53	\$1.58-\$1.63	\$1.63	\$1.43-\$1.63	\$1.43
World: Primary production	323,930	334,348	344,448	353,512	339,269

*Estimated. *Revised.

TABLE 5
MAGNESIUM RECOVERED FROM SCRAP PROCESSED
IN THE UNITED STATES,
BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1987	1988	1989	1990	1991
KIND OF SCRAP					
New scrap:					
Magnesium-base	845	2,641	3,951	3,992	4,867
Aluminum-base	20,867	19,926	19,278	19,464	18,450
Total	21,712	22,567	23,229	23,456	23,317
Old scrap:					
Magnesium-base	3,857	3,882	4,269	4,277	4,443
Aluminum-base	19,595	23,758	23,702	26,796	25,153
Total	23,452	27,640	27,971	31,073	29,596
Grand total	45,164	50,207	51,200	54,529	52,913
FORM OF RECOVERY					
Magnesium alloy ingot ¹	4,001	3,930	4,494	4,290	4,604
Magnesium alloy castings	447	438	795	857	1,043
Magnesium alloy shapes	—	1,065	635	301	158
Aluminum alloys	40,711	43,827	43,125	46,528	43,976
Zinc and other alloys	W	W	W	W	3
Chemical and other dissipative uses	W	943	W	W	W
Cathodic protection	—	—	W	W	W
Total	45,164	50,207	51,200	54,529	52,913

W Withheld to avoid disclosing company proprietary data; included in "FORM OF RECOVERY: Total."

¹Includes secondary magnesium content of both secondary and primary alloy ingot.

TABLE 6
U.S. CONSUMPTION OF PRIMARY MAGNESIUM, BY USE

(Metric tons)

Use	1987	1988	1989	1990	1991
For structural products:					
Castings:					
Die	3,710	4,383	5,627	7,479	7,532
Permanent mold	1,121	943	811	875	750
Sand	1,454	1,743	1,017	724	575
Wrought products:					
Extrusions	6,804	6,907	6,712	7,848	6,387
Other ¹	1,496	3,231	2,941	3,096	2,415
Total	14,585	17,207	17,108	20,022	17,659
For distributive or sacrificial purposes:					
Alloys:					
Aluminum	52,172	53,671	53,821	45,060	45,809
Other	8	7	9	8	9
Cathodic protection (anodes)	5,537	6,234	5,474	5,421	4,976
Chemicals	1,047	780	594	800	695
Iron and steel desulfurization	*10,000	W	10,463	9,853	10,895
Nodular iron	1,811	2,037	1,635	1,424	1,074
Reducing agent for titanium, zirconium, hafnium, uranium, beryllium	5,286	8,467	10,798	8,989	6,071
Other ²	4,174	12,390	5,324	4,531	4,684
Total	80,035	83,586	88,118	76,086	74,213
Grand total	94,620	100,793	105,226	96,108	91,872

*Estimated. W Withheld to avoid disclosing company proprietary data; included in "Other."

¹Includes sheet and plate and forgings.

²Includes scavenger, deoxidizer, and powder.

TABLE 7
U.S. STOCKS AND CONSUMPTION OF NEW AND OLD MAGNESIUM SCRAP¹

(Metric tons)

Year	Stocks, Jan. 1	Receipts	Consumption			Stocks, Dec. 31
			New scrap	Old scrap	Total	
1990	699	6,913	2,948	4,277	7,225	387
1991	387	8,059	3,669	4,443	8,112	334

¹Cast scrap, solid wrought scrap, borings, turnings, and drosses.

TABLE 8
U.S. EXPORTS OF MAGNESIUM, BY COUNTRY

Country	Waste and scrap		Metal		Alloys (gross weight)		Powder, sheets, tubing, ribbons, wire, other forms (gross weight)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1990:								
Argentina	—	—	432	\$1,337	—	—	40	\$163
Australia	—	—	2,468	7,175	—	—	149	639
Bahrain	—	—	507	1,277	—	—	—	—
Brazil	244	\$797	425	1,401	53	\$135	95	290
Canada	42	107	5,246	15,886	3,325	9,786	1,033	4,706
China	—	—	267	726	—	—	(¹)	29
Germany, Federal Republic of	20	45	—	—	54	267	175	2,556
Ghana	—	—	122	366	—	—	—	—
Hong Kong	—	—	39	116	199	1,612	1	12
India	—	—	184	421	1	11	24	174
Italy	55	162	91	1,108	318	888	5	62
Japan	9	17	11,839	39,379	56	458	519	3,721
Korea, Republic of	—	—	873	2,206	129	664	442	1,115
Mexico	285	641	1,221	3,508	91	245	667	1,699
Netherlands	169	424	14,721	38,215	289	741	231	761
Norway	—	—	924	2,431	(¹)	14	(¹)	7
Spain	—	—	650	2,412	—	—	(¹)	3
Sweden	—	—	243	782	1	40	34	131
Taiwan	—	—	591	1,587	3	17	23	116
Turkey	125	288	—	—	(¹)	4	7	26
United Arab Emirates	—	—	183	505	1	12	1	5
United Kingdom	10	17	58	662	12	215	184	1,046
Venezuela	—	—	357	1,084	2	11	237	753
Other	8	24	441	2,130	99	930	485	3,113
Total	967	2,522	41,882	124,714	4,633	16,050	4,352	21,127
1991:								
Argentina	—	—	758	1,577	4	23	61	356
Australia	—	—	2,926	7,430	—	—	151	621
Bahrain	—	—	652	2,016	—	—	—	—
Brazil	—	—	398	946	1	32	265	751
Canada	260	635	4,689	13,068	2,786	7,159	749	3,899
China	—	—	20	47	—	—	—	—
Germany, Federal Republic of	—	—	1	28	3	10	35	722
Ghana	—	—	224	605	—	—	—	—
Hong Kong	—	—	546	1,549	19	259	(¹)	3
India	—	—	505	1,330	—	—	59	636
Italy	—	—	89	1,352	—	—	—	—
Japan	17	30	12,712	33,439	56	356	566	4,019
Korea, Republic of	—	—	828	2,107	59	231	4,785	1,769
Mexico	391	879	1,262	3,140	71	252	453	1,046
Netherlands	125	373	14,956	42,510	22	80	264	411
Norway	—	—	81	290	2	9	—	—
Spain	—	—	774	2,684	—	—	1	25
Sweden	—	—	87	582	2	4	1	11

See footnotes at end of table.

TABLE 8—CONTINUED
U.S. EXPORTS OF MAGNESIUM, BY COUNTRY

Country	Waste and scrap		Metal		Alloys (gross weight)		Powder, sheets, tubing, ribbons, wire, other forms (gross weight)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1991—Continued:								
Taiwan	—	—	613	\$1,572	21	\$83	47	\$150
Turkey	85	\$294	15	97	—	—	2	9
United Arab Emirates	—	—	359	1,100	—	—	4	7
United Kingdom	36	82	57	646	37	379	207	946
Venezuela	—	—	55	129	1	4	2	5
Other	5	11	252	1,604	149	1,251	497	2,660
Total	919	2,304	42,859	119,848	3,233	10,132	8,149	18,046

¹Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF MAGNESIUM, BY COUNTRY

Country	Waste and scrap		Metal		Alloys (magnesium content)		Powder, sheets, tubing, ribbons, wire, other forms (magnesium content)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1990:								
Canada	3,346	\$7,221	14,562	\$42,489	2,436	\$9,540	57	\$224
France	—	—	248	688	2	37	—	—
Germany, Federal Republic of	64	105	—	—	2	29	—	—
Italy	34	78	—	—	36	98	—	—
Mexico	214	161	33	82	—	—	1,107	3,981
Netherlands	281	434	—	—	—	—	—	—
Norway	—	—	1,166	3,481	2,624	7,946	—	—
United Kingdom	1	2	—	—	238	2,911	32	208
Other	135	136	130	285	6	165	1	7
Total	4,075	8,137	16,139	47,025	5,344	20,726	1,197	4,420
1991:								
Canada	3,035	3,484	21,234	50,849	4,037	12,611	173	502
France	19	27	159	418	5	180	—	—
Germany, Federal Republic of	387	440	—	—	—	—	(¹)	2
Italy	122	169	—	—	11	9	—	—
Mexico	89	53	120	338	—	—	1,147	4,129
Netherlands	255	247	—	—	—	—	—	—
Norway	—	—	245	581	371	1,295	(¹)	2
United Kingdom	20	28	—	—	168	1,684	32	208
Other	223	205	—	—	4	124	7	23
Total	4,150	4,653	21,758	52,186	4,596	15,903	1,359	4,866

¹Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 10
WORLD ANNUAL PRIMARY MAGNESIUM PRODUCTION CAPACITY,¹
DECEMBER 31, 1991,
BY CONTINENT AND COUNTRY

(Metric tons)

Continent and country	Capacity
North America:	
United States	179,000
Canada	54,000
Total	233,000
South America: Brazil	
	10,600
Europe:	
France	15,000
Italy	10,000
Norway	41,000
U.S.S.R.	² 214,000
Yugoslavia	7,000
Total	287,000
Asia:	
China	9,000
India	600
Japan	13,000
Total	22,600
World total	553,200

¹Includes capacity at operating plants as well as at plants on standby basis.

²Includes 90,000 tons of annual magnesium production that is used exclusively for titanium production.

TABLE 11
MAGNESIUM: WORLD PRIMARY PRODUCTION, BY COUNTRY¹

(Metric tons)

Country	1987	1988	1989	1990	1991 [*]
Brazil	5,488	5,865	6,200	[*] 6,500	7,800
Canada [*]	8,800	7,600	7,200	[*] 26,726	35,500
China [*]	3,000	3,200	[*] 3,600	[*] 5,800	6,000
France	13,601	13,776	14,600	[*] 14,600	14,000
Italy	7,626	5,436	5,469	[*] 5,700	4,800
Japan	8,180	9,012	8,381	12,843	² 11,559
Norway	56,907	50,300	49,827	48,222	² 44,322
U.S.S.R. [*]	90,000	91,000	91,000	88,000	80,000
United States	124,396	141,983	152,066	139,333	² 131,288
Yugoslavia	5,932	6,176	[*] 6,105	[*] 5,788	4,000
Total	[*]323,930	[*]334,348	[*]344,448	[*]353,512	339,269

^{*}Estimated. ^{*}Revised.

¹Table includes data available through June 23, 1992.

²Reported figure.

TABLE 12
MAGNESIUM: WORLD SECONDARY PRODUCTION, BY COUNTRY¹

(Metric tons)

Country	1987	1988	1989	1990	1991 [*]
Brazil	1,376	1,519	¹ 1,500	¹ 1,600	1,600
Japan	¹ 10,124	¹ 15,099	² 20,270	² 23,308	² 17,158
U.S.S.R. [*]	8,000	8,000	8,000	7,500	7,000
United Kingdom [*]	1,000	1,000	1,000	1,000	1,000
United States	45,165	50,207	51,200	¹ 54,529	² 52,913
Total	¹ 65,665	¹ 75,825	¹ 81,970	¹ 87,937	79,671

^{*}Estimated. ¹Revised.

¹Table includes data available through June 23, 1992.

²Reported figure.

TABLE 13
SALIENT MAGNESIUM COMPOUND STATISTICS

(Thousand metric tons and thousand dollars)

	1987	1988	1989	1990	1991
United States:					
Caustic-calcined and specified magnesias:¹					
Shipped by producers:²					
Quantity	103	124	135	135	154
Value	\$27,565	\$36,500	\$39,529	\$37,850	\$48,074
Exports, value ³	\$14,167	\$13,322	\$2,263	\$1,406	\$2,289
Imports for consumption, value ³	\$4,575	\$2,371	\$13,657	\$13,957	\$15,891
Refractory magnesia:					
Shipped by producers:²					
Quantity	296	371	348	335	296
Value	\$80,760	\$103,400	\$97,673	\$94,962	\$85,292
Exports, value	\$3,240	\$9,262	\$10,685	\$19,709	\$25,038
Imports for consumption, value	\$41,333	\$42,885	\$38,555	\$32,858	\$30,209
Dead-burned dolomite:					
Sold and used by producers:					
Quantity	259	413	365	342	308
Value	\$21,766	\$30,182	\$28,294	\$26,988	\$25,736
World production (magnesite)	¹ 11,988	¹ 11,991	¹ 11,796	¹ 11,117	¹ 10,944

^{*}Estimated. ¹Revised.

¹Excludes caustic-calcined magnesia used in the production of refractory magnesia.

²Includes magnesia used by producers.

³Caustic-calcined magnesia only.

TABLE 14
U.S. MAGNESIUM COMPOUNDS SHIPPED AND USED

	1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Caustic-calcined ¹ and specified (USP and technical) magnesiias	134,727	\$37,850	153,655	\$48,074
Magnesium hydroxide [100% Mg(OH) ₂] ¹	366,016	69,280	302,244	82,768
Magnesium sulfate (anhydrous and hydrous)	55,411	17,366	34,872	12,229
Precipitated magnesium carbonate ¹	2,821	703	3,360	746
Refractory magnesia	335,341	94,962	296,173	85,292

¹Excludes material produced as an intermediate step in the manufacture of other magnesium compounds.

TABLE 15
YEAREND MAGNESIUM COMPOUND PRICES

Material	Price
Magnesia, natural, technical, heavy, 85%, f.o.b. Nevada	per short ton \$232
Magnesia, natural, technical, heavy, 90%, f.o.b. Nevada	do. 265
Magnesia, dead-burned	392
Magnesia, synthetic technical	330
Magnesium chloride, hydrous, 99%, flake	do. 290
Magnesium carbonate, light, technical (freight equalized)	per pound \$0.73- .78
Magnesium hydroxide, National Formulary, powder (freight equalized)	do. .78
Magnesium sulfate, technical epsom salts)	do. .15

Source: Chemical Marketing Reporter.

TABLE 16
U.S. EXPORTS OF CRUDE AND PROCESSED MAGNESITE, BY
COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Caustic-calcined magnesia:				
Canada	66	\$30	256	\$514
Germany, Federal Republic of	351	262	521	350
Mexico	170	92	123	62
Netherlands	1,444	800	699	407
United Kingdom	14	8	158	158
Venezuela	—	—	1,530	475
Other	268	214	353	323
Total	2,313	1,406	3,640	2,289
Dead-burned and fused magnesia:				
Argentina	54	56	194	137
Belgium	326	112	4,468	1,965
Canada	53,742	16,990	41,632	14,919
France	1,253	321	255	65
Germany, Federal Republic of	—	—	971	439
Israel	569	397	1,460	1,213
Japan	—	—	7,441	1,672
Korea, Republic of	424	229	302	196
Mexico	577	819	2,454	1,306
Taiwan	388	157	416	177
Venezuela	993	449	6,107	2,483
Other	284	179	592	466
Total	58,610	19,709	66,292	25,038
Other magnesia:				
Australia	164	201	152	210
Brazil	49	50	14	13
Canada	26,672	9,679	5,185	2,884
Colombia	229	388	219	347
France	820	274	805	306
Germany, Federal Republic of	101	58	142	100
Israel	6	38	17	10
Italy	203	156	150	123
Korea, Republic of	131	125	135	113
Mexico	6,396	2,864	13,416	6,010
Netherlands	216	76	158	128
Panama	71	57	1	4
Spain	1,320	688	1,592	864
Sweden	174	87	30	45
Taiwan	179	83	187	99
Thailand	191	104	62	72
United Kingdom	256	309	1,561	1,161
Venezuela	353	217	1,058	632
Other	216	655	265	864
Total	37,747	16,108	25,149	13,985

See footnote at end of table.

TABLE 16—CONTINUED
U.S. EXPORTS OF CRUDE AND PROCESSED MAGNESITE, BY
COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Crude magnesite:				
Australia	77	\$90	99	\$99
Belgium	204	454	42	131
Brazil	404	1,114	325	621
Canada	309	127	1,173	310
Germany, Federal Republic of	708	1,032	836	1,037
Greece	162	192	54	70
Hong Kong	195	171	136	112
Italy	895	1,105	612	719
Japan	1	3	108	128
Korea, Republic of	125	74	320	198
Martinique	519	83	—	—
Mexico	1,033	426	1,391	476
Netherlands	1,107	1,213	936	712
New Zealand	288	194	122	123
Spain	435	498	221	206
Taiwan	395	473	54	74
Venezuela	836	250	1,349	301
Other	316	561	183	250
Total	8,009	8,060	7,961	5,567
Calcined dolomite:				
Canada	1,398	277	2,350	464
Colombia	200	25	775	111
Dominican Republic	—	—	43	15
Germany, Federal Republic of	360	122	—	—
Mexico	7,658	1,594	9,461	2,199
Saudi Arabia	505	60	2,014	295
Trinidad and Tobago	—	—	355	43
Venezuela	—	—	1,653	189
Other	258	135	51	33
Total	10,379	2,213	16,702	3,349

Revised.

Source: Bureau of the Census.

TABLE 17
U.S. EXPORTS OF MAGNESIUM COMPOUNDS

Year	Magnesium hydroxide and peroxide		Magnesium chloride (anhydrous and other)		Magnesium sulfate (natural kieserite and epsom salts)		Magnesium sulfate (other)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989	12,072	\$3,673	2,201	\$1,812	95	\$96	483	\$519
1990	6,342	6,245	4,763	6,468	241	393	2,816	1,059
1991	2,691	4,190	2,995	2,134	808	497	2,419	1,201

Source: Bureau of the Census.

TABLE 18
U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND PROCESSED
MAGNESITE, BY COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Caustic-calcined magnesia:				
Canada	48,859	\$9,988	51,209	\$10,654
China	18,896	1,525	41,997	3,124
Greece	9,939	1,406	8,249	1,018
Japan	81	101	3,962	741
Mexico	2,390	325	2,331	317
Spain	2,200	266	—	—
Turkey	1,482	328	—	—
Other	38	18	100	37
Total	83,885	13,957	107,848	15,891
Dead-burned and fused magnesia:				
Canada	3,743	2,095	2,384	1,233
China	67,905	7,293	74,358	9,610
Czechoslovakia	2,549	374	3,706	364
Greece	28,242	4,079	21,687	2,805
Ireland	7,892	2,694	2,101	750
Israel	7,592	2,818	7,932	3,244
Italy	—	—	2,000	455
Japan	6,616	2,451	5,087	2,284
Mexico	24,954	9,224	27,128	9,300
Netherlands	2,110	683	—	—
United Kingdom	3,233	1,008	126	162
Other	174	139	21	2
Total	155,010	32,858	146,530	30,209
Other magnesia:				
Brazil	—	—	58	48
Canada	280	57	15	28
China	162	347	596	1,264
Germany, Federal Republic of	101	299	128	202
Israel	602	1,382	682	1,282
Japan	3,440	5,972	2,386	4,631
United Kingdom	148	195	135	172
Other	304	321	109	85
Total	5,037	8,573	4,109	7,712
Crude magnesite:				
Canada	52	7	—	—
China	23	4	37	11
Denmark	100	23	—	—
France	18	10	—	—
Germany, Federal Republic of	524	66	59	23
Italy	622	180	632	211
Japan	526	360	1,117	414

See footnote at end of table.

TABLE 18—CONTINUED
**U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND PROCESSED
 MAGNESITE, BY COUNTRY**

Country	1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Crude magnesite—Continued				
Other	92	\$72	111	\$53
Total	1,957	722	1,956	712
Calcined dolomite:				
Canada	38,074	3,596	27,261	3,282
Germany, Federal Republic of	36	11	590	83
Mexico	331	32	—	—
Other	—	—	1	5
Total	38,441	3,639	27,852	3,370

Revised.

Source: Bureau of the Census.

TABLE 19
U.S. IMPORTS FOR CONSUMPTION OF MAGNESIUM COMPOUNDS

Year	Magnesium hydroxide and peroxide		Magnesium chloride (anhydrous and other)		Magnesium sulfate (natural kieserite)		Magnesium sulfate (natural epsom salts)		Magnesium sulfate (other)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989	1,792	\$3,091	5,994	\$1,202	11,781	\$540	166	\$33	9,269	\$2,076
1990	3,548	5,456	6,914	1,477	12,548	612	44	37	9,992	1,656
1991	3,842	6,355	7,184	1,691	16,727	596	107	14	6,524	1,265

Source: Bureau of the Census.

TABLE 20
WORLD MAGNESIUM COMPOUNDS ANNUAL PRODUCTION
CAPACITY,¹ DECEMBER 31, 1991

(Thousand metric tons, MgO equivalent)

Country	Raw material	
	Magnesite	Seawater or brines
North America:		
United States	100	875
Canada	160	—
Mexico	—	160
Total	260	1,035
South America: Brazil		
	345	—
Europe:		
Austria	655	—
Czechoslovakia	726	—
France	—	30
Greece	240	—
Ireland	—	100
Italy	—	130
Netherlands	—	100
Norway	—	25
Poland	10	—
Spain	205	—
Turkey	309	—
U.S.S.R.	2,100	100
United Kingdom	—	200
Yugoslavia	240	—
Total	4,485	685
Africa:		
Kenya	170	—
South Africa, Republic of	119	—
Zimbabwe	2	—
Total	291	—
Asia:		
China	1,050	10
India	214	—
Israel	—	70
Japan	—	500
Korea, North	1,250	—
Korea, Republic of	—	50
Nepal	150	—
Total	2,664	630
Oceania: Australia		
	200	—
Grand total	8,245	2,350

¹Includes capacity at operating plants as well as at plants on standby basis.

TABLE 21
MAGNESITE: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country	1987	1988	1989	1990	1991 ^a
Australia	53,941	56,446	⁵ 55,000	⁶ 60,000	60,000
Austria	946,943	1,121,585	¹ 1,024,942	¹ 1,179,162	1,110,000
Brazil ²	390,182	404,126	259,508	² 257,159	350,000
Canada ³	150,000	150,000	150,000	150,000	140,000
China ^a	² 2,630,000	² 2,610,000	² 2,600,000	² 2,600,000	2,600,000
Colombia	15,444	17,760	20,425	² 20,425	20,000
Czechoslovakia	671,000	630,786	⁶ 642,000	⁵ 561,000	550,000
Greece	⁸ 841,604	⁸ 847,911	⁹ 903,593	⁹ 900,000	900,000
India	430,000	507,873	479,530	⁴ 491,000	500,000
Iran ⁴	⁵ 5,161	² 2,777	⁶ 6,967	¹ 1,405	2,000
Korea, North ^a	1,500,000	1,500,000	1,500,000	1,500,000	1,600,000
Mexico	7,351	7,538	4,229	⁵ 79	600
Nepal	38,388	45,000	27,978	² 25,000	25,000
Pakistan	3,824	3,081	8,750	⁴ 2,274	4,000
Philippines	⁶ 650	⁷ (²)	⁴ 4,796	⁷ 700	700
Poland	22,300	² 23,867	² 24,133	² 23,000	22,000
South Africa, Republic of	74,961	74,088	75,695	104,182	⁹ 2,634
Spain ^a	710,000	⁶ 624,216	620,000	600,000	500,000
Turkey	1,189,667	1,125,844	1,238,123	⁸ 812,660	825,000
U.S.S.R. ^a	1,875,000	1,825,000	1,825,000	1,600,000	1,400,000
United States	W	W	W	W	W
Yugoslavia	⁴ 402,976	³ 382,606	² 292,302	¹ 194,119	210,000
Zimbabwe	28,991	30,121	33,423	³ 32,639	32,000
Total	¹ 11,988,383	¹ 11,990,625	¹ 11,796,394	¹ 11,117,304	10,943,934

^aEstimated. ^bRevised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

¹Figures represent crude salable magnesite. In addition to the countries listed, Bulgaria produced magnesite, but output is not reported quantitatively, and available general information is inadequate for formulation of reliable estimates of output levels. Table includes data available through May 5, 1992.

²Series reflects output of marketable concentrates. Production of crude ore was as follows, in metric tons: 1987—860,163; 1988—810,837; 1989—1,385,565; 1990—1,432,741 (revised); and 1991—1,500,000 (estimated).

³Magnesian dolomite and brucite. Figures are estimated on the basis of reported tonnage dollar value.

⁴Year beginning Mar. 21 of that stated.

⁵Revised to zero.

⁶Reported figure.

TABLE 22
MAGNESIUM SUPPLY-DEMAND RELATIONSHIPS
(Thousand metric tons of contained magnesium)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
WORLD PRODUCTION											
United States:											
Nonmetal	690	512	567	574	420	412	464	573	513	499	442
Metal	140	93	104	144	136	125	124	142	152	139	131
Total	830	605	671	718	556	537	588	715	665	638	573
Rest of world:											
Nonmetal	4,668	4,371	4,777	4,676	4,807	5,009	4,905	4,956	4,900	4,704	3,654
Metal	169	161	156	184	189	196	200	192	192	215	208
Total	4,837	4,532	4,933	4,860	4,996	5,205	5,105	5,148	5,092	4,919	3,862
World total	5,667	5,137	5,604	5,578	5,552	5,742	5,693	5,863	5,757	5,557	4,435
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
U.S. production:											
Nonmetal	690	512	567	574	420	412	464	573	513	499	442
Primary metal	140	93	104	144	136	125	124	142	152	139	131
Secondary metal (old scrap)	22	21	23	24	24	23	23	28	28	31	30
Imports:											
Nonmetal	50	39	61	115	134	160	164	198	171	147	156
Metal	6	5	5	9	8	8	11	14	12	27	32
Industry stocks, metal, Jan. 1	44	57	42	25	32	39	39	28	25	26	26
Total U.S. supply	952	727	802	891	754	767	825	983	901	869	817
Distribution of U.S. supply:											
Exports:											
Nonmetal	32	20	15	27	25	25	20	34	26	59	57
Metal	32	36	43	44	36	40	44	50	57	52	55
Industry stocks, metal, Dec. 31	57	42	25	32	39	39	28	25	26	26	27
Industrial demand¹	831	629	719	788	654	663	733	874	792	732	678
U.S. DEMAND PATTERN											
Nonmetal:											
Chemicals	99	85	105	131	127	171	155	202	188	174	187
Refractories	609	446	508	531	402	376	453	535	470	413	354
Total	708	531	613	662	529	547	608	737	658	587	541
Metal:											
Cans and containers	20	17	19	23	23	22	39	39	42	45	45
Chemicals	8	6	7	8	5	3	2	1	1	1	1
Iron and steel desulfurization	NA	NA	NA	10	12	12	13	15	15	16	13
Iron and steel foundries	5	4	3	4	3	3	2	3	2	1	1
Machinery	34	33	34	29	22	27	19	20	17	20	21
Nonferrous metal production	13	7	6	9	12	9	5	11	12	11	7
Transportation	38	25	31	36	38	33	38	38	36	38	37
Other	5	6	6	7	10	7	7	10	9	13	12
Total	123	98	106	126	125	116	125	137	134	145	137
Total industrial demand	831	629	719	788	654	663	733	874	792	732	678
Total U.S. primary demand²	809	608	696	764	630	640	710	846	764	701	648
Total U.S. demand for primary metal³	101	77	83	102	101	93	102	109	106	114	107

¹Estimated. ²Revised. NA Not available.

²Sum of total nonmetal and total metal demands.

³Total U.S. demand less U.S. recovery from secondary metal.

⁴U.S. demand for metal less U.S. recovery from secondary metal.

MANGANESE

By Thomas S. Jones

Dr. Jones, a physical scientist with more than 30 years industry and U.S. Bureau of Mines experience, has been the commodity specialist for manganese since 1982. Domestic survey data were prepared by Glenn Wallace, statistical assistant; and the international data table was prepared under the direction of William Zajac, Chief, Section of International Data.

Manganese is essential to iron and steel production by virtue of its sulfur-fixing, deoxidizing, and alloying properties. Currently, no practical approaches exist for replacing it by other materials or for obtaining the bulk of U.S. requirements from domestic sources. The steel industries and economies of Japan and Western Europe are in much the same position relative to manganese as are those of the United States.

Ironmaking and steelmaking continued to account for about 90% of domestic manganese demand in 1991. For ore, rate and quantity of use in pig iron production were significantly lower than those in 1990. The quantity of U.S. imports of ore listed in table 1 was the least since 1982, whereas that of silicomanganese rose to a new record. Government inventories of manganese, all forms, were only minimally diminished and still represented more than 2 years of apparent consumption. U.S. strategic concerns about manganese were lessened by political developments relating to the Republic of South Africa and the former U.S.S.R.

In metallurgical applications, the main component of manganese demand, market conditions were generally subdued worldwide in 1991. The actual price of metallurgical-grade manganese ore declined slightly after 3 successive years of substantial advances. The price remained sufficiently high to support consideration of reactivating various former mining operations and development of known but previously unutilized resources. Prominent producers of ore and ferroalloys cut back on output.

World ore production was estimated to have decreased more than one-tenth. The Minerals Bureau of the Republic of South Africa revised its previously published data on ore production. The new figures for the 1980's generally were higher, significantly so in some instances.

The level and nature of manganese use by the United States is not expected to change much in the near future. The manner and extent of effects on global manganese supply and demand were not yet clear from transition of the former U.S.S.R. from Soviet states to republics. In 1990, traditionally large ore exports by the U.S.S.R. were almost insignificant.

DOMESTIC DATA COVERAGE

Data on domestic consumption of manganese ore, exclusive of that consumed within the steel industry, are collected by means of the "Manganese Ore and Products" survey. The approximately 20 firms canvassed by means of this survey process ore by such methods as grinding and roasting or consume it in the manufacture of manganese ferroalloys, metal, and chemicals. In 1991, responses were obtained from all firms canvassed, whose collective consumption is believed to represent that of the United States except for negligible quantities consumed by other firms, if any. The aggregated consumption data so obtained were incorporated into table 5 but only displayed within totals to avoid disclosing proprietary data.

BACKGROUND

Definitions, Grades, and Specifications

Ore.—The U.S. Bureau of Mines has compiled statistics on manganese-bearing ores, concentrates, nodules, and sinter, all referred to simply as "ore," by manganese content as follows: manganese ore, 35% or more manganese; manganiferous ore, less than 35% but not less than 5% manganese; and within the latter ferruginous manganese ore, 10% to 35% manganese; and manganiferous iron ore, 5% to 10% manganese.

Manganese ore may be considered as metallurgical, chemical, or battery grade. Metallurgical-grade material has an approximate manganese content range of 38% to 55% and may differ from chemical-grade ore only in physical form. Chemical- and battery-grade ores are often categorized by manganese dioxide (MnO_2) content, which typically is in the range of 70% to 85% (44% to 54% Mn). The U.S. Government maintains specifications for metallurgical, chemical, and battery grades of ore for stockpile purposes; industry has no corresponding standards.

Ferroalloys and Metal.—Ferromanganese is a manganese-iron-carbon alloy classified according to decreasing carbon content into standard or high-carbon grades, medium-carbon grades, and low-carbon grades. Silicon is also specified in silicomanganese (such as 18%) and ferromanganese-silicon (about 30%). For U.S. tariff purposes,

ferroalloys are required to have an iron content of 4% or greater; a manganese material with less iron would be treated as manganese metal. The specifications the U.S. industry generally follows for manganese ferroalloys and metal are those of the American Society for Testing and Materials.

Products for Trade and Industry

Metallurgical-grade ore is used primarily in making ferroalloys, pig iron, and steel. In making ferroalloys, ore with a relatively high manganese and low phosphorus content is particularly desirable.

The sulfur-fixing, deoxidizing, and alloying attributes of manganese, whose atomic weight is 54.94, are obtained mostly through use of intermediate forms such as ferromanganese. Manganese ferroalloys for use in steelmaking are selected on the basis of cost per manganese unit, allowable steel carbon and silicon specifications, and steelmaking practice. For 1991, with the cost of manganese in metallurgical ore taken as 1.0, the corresponding approximate costs per manganese unit were 2.0 for high-carbon ferromanganese, 1.8 for silicomanganese, 3.2 for medium-carbon ferromanganese, and 6.2 for manganese metal. Metallic manganese is little used per se because it is typically brittle and unworkable.

Manganese is added to aluminum principally by use of briquets of compacted aluminum and manganese powders that typically contain 75% Mn. Electrolytic manganese metal and aluminum-manganese master alloys that typically contain 25% Mn are also used for this purpose.

Various manganese dioxide-types of material, possibly ground, are used for batteries and other applications. These include natural mineral product (NMD) and synthetic dioxide produced either electrolytically (EMD) or chemically (CMD). If pure, these dioxides would contain 63.2% Mn.

Other manganese materials and some of their uses include manganese sulfate ($MnSO_4$) and manganous oxide (MnO)

for animal feed and soil conditioners, ground manganese ore for brick coloring, and potassium permanganate ($KMnO_4$) for water treatment.

Industry Structure

Makeup of the world's manganese ore producers has been chiefly as follows: Australia, Groote Eylandt Mining Co. Pty. Ltd. (GEMCO) plus recently Portman Mining Ltd.; Brazil, Cia. Vale do Rio Doce (CVRD) (including Urucum Mineração S.A.) and Indústria e Comércio de Minérios S.A. (ICOMI), plus a number of relatively small mines; China, apparently mostly small- to moderate-size operations in the eastern Provinces; Gabon, Compagnie Minière de l'Ogooué S.A. (COMILOG); Ghana, Ghana National Manganese Corp.; India, more than 200 mines, with Manganese Ore India Ltd. the most prominent company; Mexico, Cía. Minera Autlán de C.V. (Autlán); Republic of South Africa, The Associated Manganese Mines of South Africa Ltd. (AMMOSAL) and Samancor Ltd.; and the U.S.S.R., two large complexes, mining the Chiatura Basin in Georgia and the Nikopol' Basin in the Ukraine. Most ore produced goes into metallurgical applications.¹ Ore for nonmetallurgical uses generally is supplied by the large-scale producers mentioned plus smaller ones elsewhere.²

In recent years, the U.S.S.R. had been supplying more than 1 million tons³ of ore annually to Eastern Europe. However, such exports were only about 800,000 tons in 1987 and dropped precipitously to 141,000 tons in 1990. Radical political changes in Eastern Europe and the U.S.S.R. cast considerable uncertainty on the future of exports from the new republics of Georgia and Ukraine that formerly were the source of the U.S.S.R.'s exports. Otherwise, the supply of ore to the international market has been from an oligopolistic-like group of countries consisting of Australia (GEMCO), Brazil (ICOMI and CVRD), Gabon (COMILOG), and the Republic of South Africa (AMMOSAL and Samancor).

Smelting of ore into manganese ferroalloys is much more diversified than ore production. Leading ferroalloy producers are as follows: Brazil, Cia. Paulista de Ferro-Ligas (a number of plants); China, many plants; France, Société du Ferromanganèse de Paris-Outreau (SFPO); Federal Republic of Germany, Thyssen Stahl AG; Japan, Japan Metals & Chemicals Co. Ltd. and Mizushima Ferroalloy Co. Ltd.; Mexico, Autlán; Norway, Elkem A/S; Republic of South Africa, Metalloys Ltd., a subsidiary of Samancor; and the U.S.S.R., a number of plants. The U.S.S.R. has been by far the largest producer.

Four market economy countries (MEC's) currently produce metal, all electrolytically, in decreasing order of capacity: the Republic of South Africa, the United States, Japan, and, beginning in 1989, Brazil. China and the U.S.S.R. produced metal, including that obtained metallothermally in the U.S.S.R. World productive capacity for metal was given as 84,000 tons annually as of 1985⁴ and would be approximately the same in 1991.

Annual world capacity for EMD was assessed as 218,000 tons in 1989, including capacities of 78,000 tons for Japan and 39,000 tons for the United States.⁵ The main change since has been the establishment of a new plant in Australia with an annual capacity of about 20,000 tons. The principal producer of CMD is Belgium's Sedema S.A., with annual capacity of about 40,000 tons.

Geology-Resources

The world's major land-based economic resources of manganese are of two principal types: marine chemical sediments and secondary enrichment deposits.⁶ Marine chemical deposits represent a majority of known resources. In 1985, the Manganese Centre (name changed in 1989 to International Manganese Institute) estimated that known relatively high-grade deposits (those with a manganese content of at least 44%) contained about 360 million tons of manganese.⁷ As given in the

"World Review" section of this chapter, the reserve base for manganese can be considered more than 10 times this size. The world's potential supply of manganese also includes extensive marine accumulations, such as oxide nodules on deep ocean floors and oxide crusts on midocean ridges, whose commercial future is indeterminate.

Among the more common minerals occurring in manganese ores are oxides, including pyrolusite, a mineral form of manganese dioxide; the oxysilicate braunite; and rhodochrosite, a mineral manganese carbonate. Many of the minerals occurring in South Africa's Kalahari Field have been described in a recent article.⁸

Technology

Exploration.—Highly selective methods of locating land manganese deposits do not exist, but interpretation of geologic environments can assist prospecting.⁹

Mining.—Most manganese ore is produced by mechanized operations. Standard earth-moving equipment is used in surface mining. Underground mining generally is by room-and-pillar techniques. Selective mining may be practiced in producing battery- and chemical-grade ores from a deposit being worked principally for metallurgical-grade ore.

Beneficiation.—Crushing, screening, washing, jigging, and tabling as well as flotation, heavy-medium, and high-intensity magnetic separation are being or have been used to upgrade raw manganese ore into usable concentrates. Carbonate ore may be calcined. Ore fines are sintered into bulkier shapes at some ferroalloy plants, a practice being adopted increasingly by ore producers as well.

Processing.—Electrothermy is the predominant method of manufacturing manganese ferroalloys, as by the submerged-arc-furnace process.¹⁰ Blast furnace-type operations are still used in a few foreign countries to make important

quantities of high-carbon ferromanganese. Recovery of metallics other than iron from manganese-bearing ore is rare.

Manganese metal and EMD commonly are produced by electrolyzing a solution of manganese sulfate prepared from ore that has been reduction roasted. Production of the dioxide is especially sensitive to minor ore impurities.¹¹ CMD can be prepared by precipitating manganese carbonate from a sulfate solution and decomposing the carbonate to oxide.¹²

Recycling.—Scrap recovery specifically for manganese is insignificant. Considerable manganese reenters processing as a minor component of steel scrap, steel slag, and nonferrous scrap. Such recycling of manganese tends not to lead to a progressive buildup in steelmaking but it does in aluminum processing.

Economic Factors

As noted in a study by the Minerals Availability Program (MAP) of the U.S. Bureau of Mines, transportation is the most significant cost element in the production of manganese concentrates.¹³ In a recent MAP assessment of costs for most major mines in MEC's, transportation accounted for about two-thirds of concentrate cost. Transportation costs were about equally divided between transportation to the port and transportation to the market. Also according to this assessment, the major mines for metallurgical-grade ore of the MEC's are quite competitive as to ore production cost. Of the considerable resources evaluated, about 80% had estimated production costs within 20% of the lowest cost.

Operating Factors

Environmental Requirements.—In 1988, the Environmental Protection Agency (EPA) imposed an annual requirement of reporting releases to the environment of manganese chemical compounds and metal (40 CFR 372). This initially applied to operations

classifiable within Standard Industrial Classification codes 20 to 39 that annually manufacture or process at least 75,000 pounds of these materials, subject to a minimum concentration limitation. This threshold decreased to 25,000 pounds for 1989 and beyond. Also, a reporting threshold of 10,000 pounds was established for annual use of these materials other than in their manufacturing and processing.

Toxicity.—Manganese is an essential element for people, animals, and plants. For adults, a daily dietary intake in the range of 2 to 5 milligrams of manganese has been recommended, and it seems that normal diets satisfactorily meet human requirements.¹⁴ In excess, manganese can be harmful to the respiratory and nervous systems.¹⁵ Thus, manganese can be an industrial poison, but normally is not a hazard.

ANNUAL REVIEW

Legislation and Government Programs

Sanctions against the Republic of South Africa established under the Comprehensive Anti-Apartheid Act of 1986 were terminated on July 10 in accordance with Presidential Executive Order 12769 (56 FR 31855). U.S. imports of manganese materials produced in the Republic of South Africa had not been directly affected by the sanctions program throughout its duration because of the certification of manganese as an essential mineral that was unavailable from reliable and secure suppliers.

In accordance with the Deep Seabed Hard Mineral Resources Act, the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce approved 5-year extensions of the licenses and 1994-99 exploration plans for three ocean mining consortia, on July 31 for Ocean Management Inc. and Ocean Mining Associates (56 FR 37344) and on November 5 for Ocean Minerals Co. (56 FR 63716).

Strategic Considerations

Security of Supply.—Manganese, for which there is no economical substitute, is essential to steelmaking. Steel producers in the MEC's of the United States, Japan, and Western Europe have shared a common concern about lack of economically minable domestic manganese deposits. Also, MEC ore supply has been from relatively few sources, chiefly Australia, Brazil, Gabon, India, Mexico, and the Republic of South Africa, and from just one or two major ore mining companies in each of these countries. The United States has been additionally concerned about supply of manganese ferroalloys because its domestic ferroalloy industry has declined well below self-sufficiency in manganese.

Stockpile.—The status of goals and inventories of manganese materials in the National Defense Stockpile at the end of 1991 is given in table 2. The goals were unchanged from those in effect at yearend 1990. Changes in yearend inventories and sales during 1991 are summarized in table 3. The decrease in the inventory of metallurgical ore and increase in the inventory of high-carbon ferromanganese were mainly because of the stockpile upgrading program. Most of the change for high-carbon ferromanganese occurred in July when the Defense Logistics Agency accepted into inventory 74,143 tons produced under that program. Sales were only of nonstockpile grade ore, of which the largest amount, about 138,000 tons, was material being held at Butte, MT, that needed to be removed to permit Superfund cleanup activities at that site. On an overall basis, these changes only minimally reduced the reserve of contained manganese being held by the Government, which still exceeded 1.9 million tons at yearend.

Issues

The United States has been lacking in reserves and significant production of manganese almost since the start of domestic steel production. Extensive efforts to discover worthwhile ore

deposits or effective methods of using low-grade resources, including steel slags, have resulted in little commercial promise. In a 1985 report, the U.S. Congressional Office of Technology Assessment (OTA) concluded that improvements in steel production technology offered the best prospect for reducing U.S. manganese import vulnerability.¹⁶ In so doing, OTA discounted ocean mining for the present, a view shared by most participants at a December 1989 conference on marine mining.¹⁷

The setting up and maintenance of a large stockpile has been the most tangible aspect of Government manganese programs. Management of the makeup, size, and disposition of this stockpile has been a key part of Government policy. Current law limits use of the stockpile to emergency situations, but its mere presence has had economic implications. Political developments during 1991 related to two foreign countries may lead to a reevaluation from the U.S. perspective of the strategic aspects of manganese, which could have a major impact on stockpile policy. The ending of U.S. sanctions against the Republic of South Africa diminished the possibility of a sanctions-related supply disruption. The lessening of international tensions accompanying transformation of the U.S.S.R. into a commonwealth of independent republics also seemed to favor lowered concern about potential deficiencies in the U.S.'s manganese supply.

Production

Ore and Concentrate.—U.S. production and shipments consisted only of a small amount of manganiferous material for use in coloring brick. This material was mined in Cherokee County, SC, and had a natural manganese content in the range of 5% to 15%. Shipment data were not published to avoid disclosing proprietary data.

Ferroalloys, Metal, and Synthetic Dioxide.—Production statistics for these materials were not published to avoid

disclosing proprietary data. Plant sites and products are given in table 4. The only production of manganese ferroalloys, including that of high-carbon ferromanganese for the Government stockpile, was by Elkem Metals Co. at its Marietta, OH, plant. In June, Elkem Metals opened a research and development center near Pittsburgh, PA, as a replacement for a research center that was in operation for many years at Niagara Falls, NY. Programs at the new center were to include improvement of existing alloys, development of new ones, and process control technology for ferroalloys production.

Rayovac Corp. ended manufacturing operations at its plant at Covington, TN, in July. Activities there have included production of EMD and grinding of manganese ore, mostly for consumption in dry cell battery manufacture elsewhere within Rayovac. The plant had an annual capacity for EMD of about 5,500 tons, the smallest of the four domestic plants then operating. Factors cited as leading to closure of the plant were the ready availability of manganese-based materials at lower cost than as produced at Covington and the need for large capital and research investments at Covington.

Consumption, Uses, and Stocks

Metallurgical applications accounted for most manganese consumption, about 90% for steelmaking. This can be deduced from the data relating to manganese end use that form the basis of tables 5 and 6 plus certain other information. Table 7 presents industry averages for pounds of manganese used in ironmaking and steelmaking (including for castings) per ton of raw steel produced. For 1991, these consumption rates, derived from the reported data in tables 5 and 6, were lower than those in 1990. The substantial drop in manganese ore usage in ironmaking reflected the trend toward lower manganese contents in hot metal. The data for ferroalloy consumption implied some shifting from ferromanganese to silicomanganese.

Relatively small quantities of manganese were used for alloying with

nonferrous metals, chiefly aluminum. For alloying with aluminum, compared to immediately prior years, the proportion of manganese added as metal was in 1991 again significantly less than for that added as manganese-aluminum briquets and other forms.

Nonmetallurgical applications for manganese included animal feed, brick coloring, dry cell batteries, manganese chemicals, and plant fertilizers.¹⁸ Chemetals Inc., directly or indirectly a supplier of manganese for all of these applications, underwent a change in ownership carried out between January and June, from Belgium's Société Générale de Belgique to COMILOG, headquartered in Paris. Chemetals' plants involved in the acquisition included those at Baltimore, MD, where manganese chemicals and other manganese products are produced, and New Johnsonville, TN, where EMD is produced.

According to the National Electrical Manufacturers Association, the year-to-year increase in value of domestic shipments of dry batteries declined to slightly more than 1% in 1991, as compared with increases of 5% to 6% in recent prior years. Within the dry battery industry, manufacturers of cells containing manganese continued striving to completely eliminate the use of mercury. To go from mercury levels of 0.025% or less to zero in alkaline cells, Rayovac in December signed an agreement with Japan's Matsushita Battery Industrial Co. that would permit Rayovac to use technology developed by Matsushita for producing alkaline cells free from mercury. The Eveready Battery Co.'s technology group in Ohio developed a mercury-and-cadmium-free alkaline battery that was being manufactured in Switzerland and marketed in Europe.

Among ownership changes in the battery industry, Duracell International Inc., a leading manufacturer of alkaline cells and headquartered in Bethel, CT, made a stock offering in May and went from private to public ownership. Not quite 3 years prior, Kohlberg Kravis Roberts & Co. had led the privatization of Duracell's businesses in acquiring

them from Kraft Inc. In March, Eastman Kodak Co. sold its battery operations in Newark, NY, that had included manufacture of lithium-manganese dioxide cells. The sale was to a small group of investors who formed Ultralife Batteries Inc. with the stated intentions of continuing and diversifying lithium battery operations at Newark.

Markets and Prices

Manganese Ore.—The price of metallurgical manganese ore receded slightly after having increased significantly for 3 years in succession. Factors helping arrest the upward trend included cutbacks in ferromanganese production, as in Canada, Germany, and Norway; halting of shipments of ore to the U.S.S.R. because of nonpayment; and downward pressure on price from ore being supplied from Western Australia. Settlement of contracts between Japanese customers and their suppliers again set the trend. F.o.b. prices for ore from Australia's GEMCO agreed upon around June 1 were a mix, with no change for high-grade lump, a decrease of about 3% for sinter containing about 54% manganese, and a decrease of about 6% for premium fines. Prices for high-grade lumpy ore from South Africa's AMMOSAL and Samancor were settled in July at a markdown of about 2% from the 1990 f.o.b. price.

The average price, c.i.f. U.S. ports, for metallurgical ore containing 48% manganese declined similarly and was assessed as \$3.72 per metric ton unit. The metric ton unit is 1% of a metric ton; i.e., 10 kilograms or alternatively 22.05 pounds of contained manganese. The price of manganese in ore in 1991 and 1990 thus can be expressed in cents per kilogram as 37.2 and 37.8, respectively, or in cents per pound as 16.9 and 17.1, respectively. The price of a metric ton of ore is obtained by multiplying the metric ton unit price by the percentage manganese content of the ore.

The ore market consists of a number of submarkets because of differences between ores according to the various end

uses such as ferroalloy production, blast furnace ironmaking, and battery manufacture. Table 8 gives the price trend for metallurgical ore during the past two decades.

Manganese Ferroalloys.—Price trends for manganese ferroalloys, as given by quotations for imports, were negative, both for average price relative to that for the prior year and for change during the year. For ferromanganese, this was attributed at least in part to lowered demand and for silicomanganese to cheap imports into Western Europe from China and Eastern Europe. In the United States, the decline in year-average price exceeded 6% for high-carbon ferromanganese and, at more than 3%, was about one-half as great for silicomanganese.

For high-carbon ferromanganese containing 78% manganese, the price range of imported material, f.o.b. Pittsburgh or Chicago warehouse, started 1991 at \$630-\$650 per long ton of alloy and declined throughout the year, to end at \$555-\$560, a decrease for the year of about 13%.

The price range for imported silicomanganese with 2% carbon, in cents per pound of alloy, f.o.b. Pittsburgh or Chicago warehouse, began 1991 at 25.75-26.5 and advanced to 27-28 as of late March. A decline began in May and lasted the rest of the year. The yearend range of 23.6-24.15 was almost 9% below that at the beginning of the year.

Domestic producer prices (Elkem Metals) given by Metals Week for high-carbon ferromanganese and silicomanganese were unchanged from those previously listed in 1989. These prices, f.o.b. plant or warehouse, were \$695 for high-carbon ferromanganese and 35 cents for silicomanganese.

Manganese Metal.—For bulk shipments of domestic material, f.o.b. shipping point, trade journal listings were the same throughout the year as already published effective mid-November 1990. Metals Week gave a price range of \$1.04-\$1.05 per pound, whereas American Metal Market gave \$1.05 per pound.

Foreign Trade

Unit values indicated that all ore exported in 1991 was metallurgical grade except for about 200 tons. No ore was reported to have been reexported. The data for ore exports listed in table 9 show a slight decrease for quantities in 1991 compared with those in 1990. On the other hand, deduction from these data of apparent transshipments of Gabonese ore to Mexico indicates exports substantially increased in 1991. Exports of ferromanganese overall and silicomanganese also were much greater in 1991 than those in the previous year. Those of ferromanganese were the greatest since 1979, among which those to Canada were more than twice the amount exported in 1990. Exports of ferromanganese containing less than 2% carbon were 11,025 tons in 1991 or almost 3 times as great as the 3,945 tons exported in 1990.

In terms of the manganese content of imports, the ratio of the sum of ferroalloy plus metal to the sum of ore plus dioxide was again larger at 3.4 than that in the previous year and the greatest since 1982. The data on imports for 1990-91 listed in table 10 signified for ore a decrease in amount of about one-fifth, with or without adjustment of the data for apparent transshipments of Gabonese ore to Mexico. The decline in 1991 was principally because of reduced receipts of ore containing less than 47% manganese, for which category no receipts were reported from Brazil or the Republic of South Africa. The overall quantity of ore imported in 1991 was the least since 1982. Manganese content averaged 50.1%, the highest since the same percentage was attained in 1987.

Imports of ferromanganese were about 16% less overall in 1991 than those in 1990, and had an average manganese content of 78.3%. Receipts of high-carbon ferromanganese from France declined about 25% and those from the Republic of South Africa about 41% to give for the Republic of South Africa the smallest quantity since 1983. Unusual items among ferromanganese imports were, for the high-carbon grade, receipts

from the Philippines and a quintupling of receipts from the United Kingdom, and, among the lower carbon grades, receipts of 412 tons from the U.S.S.R. For spiegeleisen, imports were reported as 149 tons, mostly material of high unit value from the Federal Republic of Germany; no exports were reported.

Increases in imports were registered for silicomanganese, metal, and dioxide compared with those for 1990. Silicomanganese imports increased 15% to surpass the previous record for quantity set in 1989. This advance included record receipts from Brazil and Canada. For metal, imports of unwrought material from China were almost 4 times as great as those in 1990, while those from the Republic of South Africa in the category of "metal, other" were 1.8 times as great. The amount of manganese dioxide imported was the greatest since 1988 and was nearly triple the 1990 amount. Australia, a new source, accounted for more than 40% of the total, and receipts from Ireland were more than five times as great as those in 1990. All dioxide imports were apparently synthetic material.

Among other manganese chemicals, imports of potassium permanganate in 1991 totaled about one-half as much as in 1990 and were the least since 1982. For the principal recent sources, declines were particularly pronounced for China and Spain. Under imports classified as "Other sulfates," which includes manganese sulfate, the entries for Mexico totaled 11,012 tons valued at \$5.0 million.

Tariffs.—The schedule of tariffs that applied during 1991 to U.S. imports of selected manganese materials is given in table 11.

Duty-free treatment under the Generalized System of Preferences (GSP) program was indefinitely suspended for imports from Yugoslavia effective December 24. This action, under Presidential Proclamation 6389 (56 FR 64467), imposed duties at the most-favored-nation rate. Among imports of manganese materials, the item principally affected was silicomanganese.

A ruling of the Office of the U.S. Trade Representative in June continued to deny duty-free status to imports of medium-carbon ferromanganese from Mexico. Mexico had petitioned that the import ceiling limit for medium-carbon ferromanganese be waived within the 1990 GSP product review.

Antidumping duties on potassium permanganate from China and Spain were changed in accordance with administrative reviews of 1989 imports by the International Trade Administration (ITA) of the U.S. Department of Commerce. For material from China, the margin of 39.63% that had applied since January 1984 was effectively raised to 128.94% in April (56 FR 19640). For material from Spain, the margin was lowered from 16.16% to 3.96% in November (56 FR 58361).

The ITA also determined that high-grade chemical manganese dioxide (CMD-U) from Japan was a later developed product within the scope of the already existing antidumping duty order on EMD from Japan, and therefore subject to an antidumping duty at the "All others" 73.3% rate. This decision was published in preliminary fashion in November (56 FR 56977) and affirmed in January 1992 (57 FR 395).

World Review

Capacity.—The rated capacity data in table 12 are as of December 31, 1991, and are the same as in the previous year except for Australia and the Republic of South Africa. The figure for Australia was increased to include operations in Western Australia, and that for the Republic of South Africa was increased to compensate for upward revision of data for production in past years. The data correspond to the manganese contents of ore and/or concentrates capable of being utilized, as in feed to a smelter. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable, long-term operating rate.

Reserves.—Only a few of the world's many manganese concentrations have

enough economic significance to be classed as reserves;¹⁹ no domestic deposits qualify.²⁰ World reserves of manganese, generally on the same basis as capacity, are given in table 13 with no distinction between ore type or application. The data in this table are the same as given in the 1990 Minerals Yearbook except for Australia and the Republic of South Africa. The estimates for Australia have been revised on the basis of resource data provided by Australia's Bureau of Mineral Resources. The reserve base figure for the Republic of South Africa has been changed to conform with that of the South African Minerals Bureau, which includes material with less than 30% manganese content. The data in table 13 are exclusive of perhaps 1% to 2% of total known reserves. These are in nonlisted countries having a similar proportion of world production, as can be seen from table 15.

Argentina.—Carbometal S.A.I.C., with plants at El Níhuil and Carrodilla in Mendoza Province, initiated production of manganese ferroalloys. The company's annual capacities were 5,500 tons for high-carbon ferromanganese, 1,100 tons for medium-carbon ferromanganese, and 6,600 tons for silicomanganese.

Australia.—Broken Hill Pty. Co. Ltd. (BHP) reported that manganese ore shipments to foreign and domestic destinations by its GEMCO subsidiary totaled about 1.3 million tons.²¹ This was a drastic decrease from a similar total of about 2.0 million tons in 1990. Production operations at the company's Groote Eylandt Mine in the Northern Territory likewise were significantly reduced. In November, effective from January 1, 1992, organizational changes were announced that placed all of the manganese-related operations of BHP into a BHP Manganese Division. This division became one of seven components within BHP Minerals, which itself early in 1991 had shortened its name from BHP Minerals Utah International.

Australian Manganese Co. Ltd. (AMCL), the newest operation within BHP Manganese, began exports in

February from its EMD plant near Newcastle, New South Wales, which had been brought up to full operational capacity of about 20,000 tons per year. This export-oriented plant was built in 1987-89 and was being fed with ore from GEMCO.²²

Production of manganese ore in Western Australia continued on the scale of 300,000 tons annually. This was from operations such as those in which Portman Mining Ltd. was participating in the east Pilbara region at Woodie Woodie.²³ A former manganese resource also being reactivated was that at Horseshoe, Mount Fraser, to the west center of Western Australia, by Sabminco NL.

Belgium.—The Sadacem Group within Gechem, the chemical subsidiary of Société Générale de Belgique, was acquired by COMILOG in the first part of the year. Facilities sold included those at Tertre for the manufacture of CMD, manganese sulfate, and other manganese chemicals, and at Langerbrugge (Ghent), where manganese ferroalloys have been produced. COMILOG has been involved commercially with the facilities it acquired for many years.

Brazil.—ICOMI, the manganese mining subsidiary of Cia. Auxiliar de Empresas de Mineração S.A. (Caemi), no longer was shipping high-grade lump ore containing 48% manganese from operations at Serra do Navio, Amapá Territory. Its highest grade lump product had a nominal manganese content of 46%. To better position itself as a long-term supplier, the company planned to move to Porto de Santana sizable stocks of intermediate-grade and lower grade products that had accumulated during mining. Infrastructure at the mine, for which the present concession expires in the year 2003, was expected to be shared with the University of São Paulo for studies of Amazon ecology.

Relocation of ore stocks was part of Caemi's overall program of consolidating its manganese activities at the port area, where ore sintering and ferroalloy smelting were progressing. Capacity of

the plant producing a sinter containing about 52% manganese had been raised to in excess of 100,000 tons per year. Depending on demand, the potential existed for doubling that capability. Ferromanganese output at Cia. Ferroligas do Amapá, Caemi's ferroalloy subsidiary, was reported to have been near its annual capacity of 25,000 tons.

In the Carajás region, total manganese ore shipments from the Azul Mine of CVRD through the coastal port of Ponta da Madeira decreased by about one-seventh to 414,000 tons. Although exports advanced about 13% to 291,000 tons, shipments to Brazilian consumers fell by almost one-half to 123,000 tons.²⁴

Production of manganese ferroalloys increased about 14% to set a record of 486,000 tons. Compared with outputs in 1990, only that for high-carbon ferromanganese declined, by about 2% to 165,000 tons. Production of medium- and low-carbon ferromanganese recovered by 10% to total 21,000 tons while that of silicomanganese gained about one-fourth to reach almost 300,000 tons, also a record.

In 1990, manganese ore sales by Urucum Mineração S.A., CVRD's 47%-owned subsidiary in the State of Mato Grosso do Sul, had risen more than 60% to 321,000 tons, of which 181,000 tons was exported and 140,000 tons went to domestic customers.

Burkina Faso.—InterStar Mining Group Inc., a Canadian firm, signed an agreement with the Government of Burkina Faso to develop the Tambao deposit near the northern borders with Mali and Niger. The deposit was projected to yield high-grade ore. Tambao has been known for more than 30 years, but its development has been impeded by lack of rail transport. Plans announced suggested beginning with ore production on the scale of about 80,000 tons per year using trucks where no railroad exists, followed by quadrupling of output once shipment can be made entirely by rail. Ownership of InterStar was about one-third each by two Canadian companies (Phoenix Canada Oil Co. Ltd.

and Starrex Mining Corp. Ltd.) and the public.

Canada.—The manganese smelter of Elkem Metal Canada at Beauharnois, Quebec Province, was shut down indefinitely as of the end of May. This smelter produced high-carbon ferromanganese and silicomanganese. One of the larger such smelters in the world and Canada's only producer of manganese ferroalloys, it was closed as part of a rationalization of the manganese ferroalloy operations of Elkem, the Norwegian parent. A proposal made in 1989 to form a joint venture between the Beauharnois smelter and the predominantly manganese smelter of BHP's Tasmanian Electro Metallurgical Co. Pty. Ltd. in Tasmania had not yet been consummated.

France.—Near the end of the year, Usinor-Sacilor S.A. completed an electric furnace plant for manganese ferroalloys on the coast at Dunkirk, where the company already has a steel plant. The plant's annual capacity was about 100,000 tons combined for ferromanganese and silicomanganese. Most of the output was expected to be consumed internally for steelmaking. One of the principal feed materials contracted for was ore from CVRD's Azul Mine in Brazil. Use of ore from this mine was facilitated by equipping the smelter with a unit for sintering fines.

Symptomatic of the slow market for manganese ferroalloys, SFPO was reported in the latter part of the year to be operating its blast furnace plant for high-carbon ferromanganese at Boulogne at only about two-thirds of capacity.

Gabon.—Exports of manganese ore from COMILOG's Moanda Mine decreased about one-sixth, compared with those in 1990, to 2,021,000 tons. Ocean shipments in 1991 consisted of 80 cargoes, of which 53 were via the Owendo terminal in Gabon and 27 were via the Pointe-Noire terminal in the Congo.²⁵ Like other major manganese ore producers, COMILOG cut back its

mining operations. In 1990, production of 2,671,000 tons of ore had included 69,000 tons of battery-grade ore.

Germany, Federal Republic of.—Both in the early and latter parts of the year, Thyssen Stahl shut down temporarily the production of ferromanganese from its plants in the Duisburg area. The company continued to be a significant producer of medium-carbon ferromanganese. This alloy was obtained at Thyssen's Ruhrort plant by refining in an oxygen converter high-carbon ferromanganese that had been produced in a blast furnace at its Hamborn plant.

India.—Effective April 1 at the beginning of the 1991 fiscal year, the Government broadened its ban on the export of manganese ore, previously directed at high-grade ore, to include medium-grade ore containing more than 38% manganese and less than 0.2% phosphorus.

Developments in the manganese ferroalloy industry included commercialization at midyear of a so-called high-pressure sintering process for manganese ore fines. This technology was put into operation in a 100-ton-per-day unit at the Chandrapur plant of Maharashtra Elektrosmet Ltd.²⁶ Khandelwal Ferro Alloys Ltd., with a plant also in Maharashtra State at Kanhan, installed equipment giving it the capability to produce low- and medium-carbon ferromanganese on a small scale to augment its existing output of high-carbon ferromanganese. In June, conversion was completed from production of ferromanganese to ferrochromium for one of two 9-megavolt-ampere ferromanganese furnaces at the Joda plant, Orissa State, of Tata Iron and Steel Co. That plant had had an annual ferromanganese capacity of about 40,000 tons. At Balasore, southwest of Calcutta, Ispat Alloys Ltd. started trial production in the latter part of the year from a ferromanganese-silicomanganese furnace having an annual capacity of about 20,000 tons.

Japan.—Roughly one-fifth of the manganese ore purchases contracted for in the 1991 fiscal year represented a supply diversification. The majority of material from new sources was relatively high-grade ore from the operations of Portman Mining in Western Australia. Material from Brazil's ICOMI also being tried included sinter containing about 52% manganese and low-grade fines containing about 36% manganese.

Production of manganese ferroalloys increased 4% to a total of 607,000 tons. The total consisted of 419,000 tons of high-carbon ferromanganese, the largest such quantity since 1984; 92,000 tons of low-carbon ferromanganese; and 96,000 tons of silicomanganese. In the latter part of the year, Pacific Metals discontinued its small production of ferromanganese from its plant at Hachinohe in Aomori Prefecture.

Imports of silicomanganese remained the most significant item of foreign trade in manganese ferroalloys. The 1991 import total for silicomanganese was 266,000 tons, of which more than 50% was from China. The continuing high level of imports of silicomanganese led the domestic ferroalloy producers to file an antidumping petition with the Government on October 8, which was directed against producers in China, Norway, and the Republic of South Africa. The Government began its formal investigation on November 29. Other trade data for manganese ferroalloys in 1991 included imports of ferromanganese totaling 35,900 tons, a 25% decrease from the 1990 total; exports of ferromanganese totaling 5,500 tons, a decrease of 11%; and negligible exports of silicomanganese amounting to only 72 tons.

The downward trends in 1989-90 for production and exports of EMD were reversed. Output rose about one-seventh to 64,500 tons, and exports increased almost 4% to 34,400 tons.

Production of electrolytic manganese metal decreased 11% to 4,470 tons. Imports of unwrought manganese metal, including scrap, increased by almost one-third to 19,800 tons. The Republic of South Africa and China were the most

important sources with 52% and 42%, respectively, of the total.

Mexico.—Outputs by Autlán, the principal producer of manganese ore and ferroalloys, were reduced for all such materials except battery ore. The reduction overall was roughly two-fifths for ore products and one-seventh for ferromanganese plus silicomanganese. Production from the Molango District in Hidalgo State in 1991 and 1990, respectively, consisted of 460,000 and 737,000 tons of carbonate ore, of which 73,000 and 106,000 tons were sold without nodulizing, 181,000 and 368,000 tons of oxide nodules produced by calcining carbonate ore, and 25,200 and 23,900 tons of battery ore from the Nonoalco Mine. Combined production of manganese ferroalloys from Autlán's plants at Tamós in Veracruz State and Teziutlán in Puebla State in 1991 and 1990, respectively, came to 139,000 and 170,000 tons for all types of ferromanganese and 54,100 and 58,600 tons for silicomanganese.

Norway.—The two Norwegian manufacturers of manganese ferroalloys reported production cutbacks. Both of Elkem's plants were affected, Elkem PEA at Porsgrunn and Elkem Sauda at Sauda, which together were producing all the chief manganese ferroalloys. At its Kvinesdal facility where principally silicomanganese was being produced, Tinfos Jernverk A/S shut down one of the two furnaces for maintenance for 2 months in the first half of the year.

The Government granted Elkem and Tinfos another 2-year exemption from sanctions against importing manganese ore from the Republic of South Africa. Previously, the exemption had been extended until July 20, 1991.

South Africa, Republic of.—The Minerals Bureau, which had been reviewing South African data on manganese ore production for several years, made revisions to many of its previous figures, a number of which were increased substantially. Information

furnished by the Minerals Bureau to the U.S. Bureau of Mines in February 1992 was the basis of the ore production data for the Republic of South Africa by category for 1991 in table 14 and in total for 1987-91 in table 15. Of the data listed in table 15, that for 1989 underwent one of the most pronounced revisions, as total production was increased by more than one-third.

In response to slack demand on the international ore market, Samancor stated in July that it would reduce output significantly from its Mamatwan and Wessels Mines in northern Cape Province. Manganese ore shipments by AMMOSAL from the Kalahari Field in Cape Province were 1,114,000 tons, the lowest quantity since 1987 and a further decline of more than 20% from shipments in 1990.

South African manganese ferroalloys were also produced at a reduced rate. In July, the Transalloys Div. of Highveld Steel and Vanadium Corp. Ltd. lowered the operating level for silicomanganese at its Witbank plant, Transvaal Province, to less than one-half of its annual capacity of about 200,000 tons. At about the same time and for about one-third of the year, Transalloys also took out of service its annual capacity for medium-carbon ferromanganese of about 50,000 tons. In late summer, a strike halted ferromanganese production for a time at the plant of Ferroalloys Ltd., a subsidiary of AMMOSAL. The company said shipments were unaffected from its plant at Cato Ridge, Natal Province, with an annual capacity of about 200,000 tons.

U.S.S.R.—Silicomanganese exported to Western Europe was reported to be influencing ferroalloy markets there. Quantities shipped to the European Community (EC) were several times those in 1990.

Early in the year, the Commission of the European Community allowed the provisional antidumping duty to expire on imports of potassium permanganate from the U.S.S.R. The Commission was unable to identify any direct exports of this compound from the U.S.S.R. to the EC since 1988.

Exports of ore reported for 1990 were only 141,000 tons, the smallest such quantity since at least World War II. Statistics as to destinations were not available.

Current Research

The U.S. Bureau of Mines reported on additional studies of hydrometallurgical processes for extracting manganese from low-grade domestic sources. In one investigation, countercurrent fluoride-enhanced acid leaching (hydrochloric acid plus calcium fluoride) was used to attain manganese extractions of 98% from manganese silicate-type ore. Samples were from the Silverton district, San Juan County, CO and contained 35% manganese.²⁷ Another investigation dealt with the use of fluosilicic acid (H_2SiF_6), a fertilizer industry byproduct, to leach slags generated in making steel by the basic oxygen process. Two-stage countercurrent leaching yielded manganese extractions of 73% to 83% from slags containing about 1% to 3% manganese. Based on the test results, a process was proposed by which 75% of the manganese could be recovered from such slags in the form of manganese-iron hydroxy carbonates containing 4% manganese and 32% iron.²⁸

Conditions within submerged arc furnaces being used to smelt manganese ore into ferromanganese have been studied and modeled over many years to develop ways of avoiding eruptions to which such furnaces tend to be subject. A thermochemical analysis of ferromanganese smelting was carried out on the basis of a method proposed for calculating the electrical resistance of the mix of ore, coke, and flux. From this it was concluded that a sudden decrease in carbon dioxide content of the top gas should be regarded as a sign of imminent trouble.²⁹

Current emphasis on producing steel with a low residual phosphorus content led a German steelmaker to investigate the effects of phosphorus, silicon, and manganese contents of pig iron on final phosphorus content when making pig iron into steel in an oxygen converter.

Conditions at that particular plant included use of scrap with a relatively high manganese content. It was found that higher manganese inputs did not necessarily preclude achieving a low phosphorus level, as the results also depended on iron content of the slag.³⁰

In recent years, certain Japanese steelmakers have introduced manganese as manganese ore during oxygen converting rather than as a ladle addition of ferromanganese after injection is complete. The potential of this practice, as well as use of manganese ore in blast furnaces and electric arc furnaces, was assessed by means of a thermochemical analysis. Use of manganese ore in oxygen converting was found to be favored by slag conditions of low volume, low iron oxide content, and high basicity. It was noted that the economics of using ore in place of ferromanganese were complex and site specific.³¹

Japan's Nippon Steel Corp. reported on development of improved technology for control of oxygen converting that included an on-line sensor for manganese content of the steel. Operation of the sensor was based on spectrographic analysis of the light emitted from the steel bath, which was picked up by an optical fiber system. Manganese concentration was evaluated from determination of the emission intensity of manganese relative to that of iron.³²

Carbon pickup from the mold flux can be a problem in the continuous casting of ultra-low-carbon steels, such as those with a carbon content of 0.003% or less. Tests by Japanese workers in which manganese dioxide was added to the flux as an oxidant at concentrations of up to 20% indicated this to be one of the more successful methods of dealing with this problem.³³

Egyptian workers investigated the use of native ore as a pigment for surface coatings and found such ore could economically replace iron oxide pigments in anticorrosive primers. Their tests were based on two types of samples from the Sinai Manganese Co., high-grade ore nominally containing about 44% manganese and medium-grade ore containing 18% to 28% manganese. The

samples tested had manganese contents of 58.1% and 23.4%, respectively, in both of which the dominant manganese mineral was pyrolusite.³⁴

MnBi, the intermetallic compound having equal atomic concentrations of manganese and bismuth, is potentially useful as a permanent magnet material and for other purposes. Practical application of MnBi has been impeded by the severe macrosegregation of manganese and resultant nonhomogeneity that occurs during attempts to prepare the compound using conventional casting procedures. A survey was made of alternative preparation techniques and the magnetic properties of the compositions obtained.³⁵

Information pertaining to phase equilibria in the manganese-nickel system at temperatures up to the melting point of nickel was reviewed by the U.S. Bureau of Mines. From this, a manganese-nickel phase diagram was put forth, and various aspects of phases within it were discussed.³⁶

The possibility that the chemical behavior of manganese in the oceans may have had a significant influence on the timing of the Earth's periods of glaciation was indicated by a model relating oceanic release of carbon dioxide to solar radiation. The model embodied a cycle between dissolved manganese carbonate and deposition of manganese dioxide. Data supporting the model's assumptions were obtained from manganese crusts and from manganese profiles in deep-sea sediments.³⁷

OUTLOOK

The trend of manganese demand, domestically and globally, will continue to closely follow that of steel production. Nonmetallurgical components of manganese demand, especially batteries, may experience higher growth rates than for steel production, but will have only a minor effect on overall manganese demand.

As given in table 16, U.S. apparent consumption of manganese has ranged within approximately plus or minus 10% of 700,000 tons of contained manganese

for nearly a decade. This has largely been a consequence of similar variability in domestic steel production. Manganese demand as calculated in table 16 generally has corresponded to but not traced precisely the level of activity in the steel industry. Differences in the respective year-to-year variations are believed to show the influence of unmeasured changes in stocks of manganese materials, such as those of importers, the effect of which may outweigh changes in demand by steelmakers.

The outlook for domestic steel production, as discussed in the annual report for "Iron and Steel," includes a modest improvement for 1992 over that of 1991, from which a slight pickup in manganese demand can be inferred. Forecasts of the International Iron and Steel Institute (IISI) continue to project little growth in U.S. steel output through 1995. This suggests that U.S. apparent consumption of manganese in 1992-95 is unlikely to range far from 700,000 tons of contained manganese, on the continued assumption of insignificant change in manganese unit consumption in steelmaking. The majority of U.S. demand will be met by imports.

Global forecasts of IISI and others suggest that world manganese demand during the balance of the 1990's should increase only marginally. The IISI foresees for steel consumption a static condition for industrialized countries and an increase for developing countries and China that slightly exceeds a decrease expected for the former U.S.S.R. and Eastern Europe. Some realignment of overall supply-demand relationships for ore and ferroalloy is expected from change in operating philosophy of the manganese mines and smelters and steel sector of the former U.S.S.R. Depending on the future course of ore prices, resurgence of ore production from localities such as Western Australia can add to future supply for at least a limited number of years.

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TABLE 1
SALIENT MANGANESE STATISTICS

(Thousand short tons, gross weight)

	1987	1988	1989	1990	1991
United States:					
Manganese ore (35% or more Mn):					
Exports	63	68	57	77	73
Imports for consumption	341	512	639	338	258
Consumption	*533	*554	616	548	521
Stocks, Dec. 31: Consumers	*456	*458	518	418	303
Ferromanganese:					
Exports	3	3	9	8	16
Imports for consumption	368	531	476	419	352
Consumption	409	468	440	455	381
Stocks, Dec. 31: Consumers and producers	48	91	75	62	55
World:					
Production of manganese ore	*26,404	*27,542	*29,323	*28,036	*24,666

*Estimated. Revised.

TABLE 2
U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND INVENTORIES
FOR MANGANESE MATERIALS IN 1991

(Short tons, gross weight)

Material	Stockpile goals	Physical inventory, Dec. 31			Sold, pending shipment	Grand total ¹
		Stockpile grade	Nonstockpile grade	Total		
Natural battery ore	25,000	169,511	19,425	188,936	14,787	203,723
Synthetic manganese dioxide	25,000	3,011	—	3,011	—	3,011
Chemical ore	170,000	172,655	89	172,744	417	173,161
Metallurgical ore	2,700,000	1,626,720	745,584	2,372,304	155,825	2,528,128
High-carbon ferromanganese	439,000	942,813	—	942,813	—	942,813
Medium-carbon ferromanganese	—	29,072	—	29,072	—	29,072
Silicomanganese	—	23,574	—	23,574	—	23,574
Electrolytic metal	—	14,172	—	14,172	—	14,172

¹Data may not add to totals shown because of independent rounding.

TABLE 3
SALES AND INVENTORY CHANGES FOR MANGANESE MATERIALS
IN U.S. GOVERNMENT STOCKPILE, 1991

(Short tons, gross weight)

Material	Sales		Change in yearend inventory
	Stockpile grade	Nonstockpile grade	
Natural battery ore	—	14,000	—
Metallurgical ore	—	145,959	(190,468)
High-carbon ferromanganese	—	—	74,273

TABLE 4
DOMESTIC PRODUCERS OF MANGANESE PRODUCTS IN 1991

Company	Plant location	Products ¹				Type of process
		FeMn	SiMn	Mn	MnO ₂	
Chemetals Inc.	Baltimore, MD	—	—	—	X	Chemical.
Do.	New Johnsonville, TN	—	—	—	X	Electrolytic.
Elkem Metals Co.	Marietta, OH	X	X	X	—	Electric furnace and electrolytic.
Kerr-McGee Chemical Corp.	Hamilton, MS	—	—	X	—	Electrolytic.
Do.	Henderson, NV	—	—	—	X	Do.
Ralston Purina Co.:						
Eveready Battery Co.	Marietta, OH	—	—	—	X	Do.
Rayovac Corp.: Materials Div.	Covington, TN	—	—	—	X	Do.

¹FeMn, ferromanganese; SiMn, silicomanganese; Mn, electrolytic manganese metal; MnO₂, synthetic manganese dioxide.

TABLE 5
U.S. CONSUMPTION AND INDUSTRY STOCKS
OF MANGANESE ORE,¹ BY USE

(Short tons, gross weight)

Use	Consumption		Stocks, Dec. 31	
	1990	1991	1990	1991
Manganese alloys and metal	W	W	W	W
Pig iron and steel	90,000	52,000	101,000	30,000
Dry cells, chemicals, miscellaneous ²	W	W	W	W
Total	548,000	521,000	418,000	303,000

W Withheld to avoid disclosing company proprietary data; included in "Total."

¹Containing 35% or more manganese (natural).

²Natural ore, including that consumed in making synthetic manganese dioxide.

TABLE 6
**U.S. CONSUMPTION, BY END USE, AND INDUSTRY STOCKS OF
 MANGANESE FERROALLOYS AND METAL IN 1991**

(Short tons, gross weight)

End use	Ferromanganese			Silico- manganese	Manganese metal
	High carbon	Medium and low carbon	Total		
Steel:					
Carbon	214,855	77,281	292,136	78,493	2,004
Stainless and heat-resisting	13,247	(¹)	13,247	6,142	2,808
Full alloy	28,835	6,359	35,194	17,250	460
High-strength, low-alloy	22,775	2,841	25,616	5,750	(¹)
Electric	(¹)	(¹)	(¹)	(¹)	(¹)
Tool	106	(¹)	106	(¹)	44
Unspecified	123	608	731	390	420
Total steel	279,941	87,089	367,030	108,025	5,736
Cast irons	10,353	767	11,120	1,686	—
Superalloys	W	—	W	—	130
Alloys (excluding alloy steels and superalloys)	1,048	328	1,376	W	² 18,676
Miscellaneous and unspecified	1,892	—	1,892	3,095	499
Total consumption³	293,234	88,184	381,418	⁴112,806	25,041
Total manganese content⁵	229,000	71,000	300,000	74,000	25,000
Stocks, Dec. 31:					
Consumers and producers	42,041	13,249	55,290	9,359	5,670

W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

¹Withheld to avoid disclosing company proprietary data; included with "Steel: Unspecified."

²Approximately 85% of this usage was for consumption in aluminum alloys.

³Includes estimates.

⁴Internal evaluation indicates that silicomanganese consumption is considerably understated.

⁵Estimated based on typical percent manganese content (rounded).

TABLE 7
U.S. UNIT CONSUMPTION OF MANGANESE IN
IRONMAKING AND STEELMAKING

(Pounds per ton of raw steel unless otherwise specified)

Form used	1990	1991
IRONMAKING		
Basis:		
Production of raw steel million tons ¹	98.9	87.9
Ore ²	.8	.5
STEELMAKING		
Basis:		
Production of raw steel and steel castings million tons	100.0	*89.1
Ore ²	(?)	(?)
Ferromanganese	6.8	6.5
Silicomanganese	1.4	1.6
Manganese metal	.1	.1
Total, steelmaking	8.3	8.2

*Estimated.

¹As ingots, continuous- or pressure-cast blooms, billets, slabs, etc.

²Containing 35% or more manganese.

³None reported.

TABLE 8
TIME-PRICE RELATIONSHIPS
FOR MANGANESE IN
METALLURGICAL ORE

Year	Average annual U.S. price, dollars per metric ton unit	
	Actual price	Based on constant 1987 dollars
1971	0.59	1.56
1972	.59	1.49
1973	.64	1.52
1974	.89	1.93
1975	1.36	2.69
1976	1.43	2.65
1977	1.46	2.54
1978	1.38	2.24
1979	1.38	2.06
1980	1.67	2.29
1981	1.69	2.11
1982	1.56	1.83
1983	1.36	1.53
1984	1.40	1.52
1985	1.41	1.49
1986	1.32	1.36
1987	1.27	1.27
1988	1.75	1.70
1989	2.76	2.56
1990	3.78	3.37
1991	3.72	3.18

TABLE 9
U.S. EXPORTS OF MANGANESE ORE,
FERROALLOYS, AND METAL, BY COUNTRY

Country	1990		1991	
	Gross weight (short tons)	Value (thousands)	Gross weight (short tons)	Value (thousands)
ORE AND CONCENTRATES WITH 20% OR MORE MANGANESE				
Canada	20,958	\$1,535	29,647	\$2,152
Mexico ¹	52,641	6,807	33,651	5,496
Other	3,502	955	9,776	875
Total²	77,101	9,297	73,074	8,523
FERROMANGANESE, ALL GRADES				
Belgium	295	332	400	620
Canada	5,744	4,302	13,139	11,681
Mexico	465	443	489	480
Sweden	318	316	409	428
United Kingdom	466	533	1,001	1,515
Other	³ 744	³ 639	626	690
Total²	8,032	6,565	16,064	15,414
SILICOMANGANESE				
Canada	1,141	1,031	2,147	1,932
Mexico	200	145	963	804
Trinidad and Tobago	389	249	—	—
Other	244	242	57	66
Total²	1,974	1,666	3,167	2,802
METAL, INCLUDING ALLOYS AND WASTE AND SCRAP				
Canada	1,882	5,217	1,776	4,407
Japan	1,188	2,036	178	2,005
Luxembourg	983	1,568	—	—
Netherlands	1,256	2,191	1,958	4,223
Other	1,467	3,031	1,899	2,023
Total²	6,773	14,043	5,811	12,658

¹Includes quantities believed transhipped from Gabon, about 51,000 tons in 1990 and 27,000 tons in 1991.

²Data may not add to totals shown because of independent rounding.

³Unspecified group of countries differs from that in the 1990 Minerals Yearbook.

Source: Bureau of the Census, adjusted by the U.S. Bureau of Mines.

TABLE 10
U.S. IMPORTS FOR CONSUMPTION OF MANGANESE ORE, FERROALLOYS,
METAL, AND SELECTED CHEMICALS, BY COUNTRY

Country	1990			1991		
	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)
ORE AND CONCENTRATES WITH 20% OR MORE MANGANESE						
All grades						
Australia	68,986	35,873	\$9,201	36,334	18,172	\$4,620
Brazil	51,895	22,776	3,170	5,373	2,847	407
Canada ¹	—	—	—	12	6	4
Gabon ²	150,059	74,766	20,928	174,920	88,182	29,801
Ghana	5,589	2,515	434	11,389	5,064	1,209
Mexico ³	7,309	3,012	885	11,669	5,151	1,356
Morocco	39	20	11	96	49	25
Norway ⁴	25,822	14,242	3,553	17,992	9,780	2,911
South Africa, Republic of	28,504	10,977	1,871	—	—	—
Total⁶	338,200	164,180	40,054	257,787	129,252	40,332
More than 20% but less than 47% manganese						
Brazil	35,919	15,049	973	—	—	—
Ghana	5,589	2,515	434	11,389	5,064	1,209
Mexico ³	7,309	3,012	885	8,401	3,419	949
South Africa, Republic of	28,504	10,977	1,871	—	—	—
Total⁶	77,320	31,552	4,164	19,790	8,483	2,158
47% or more manganese						
Australia	68,986	35,873	9,201	36,334	18,172	4,620
Brazil	15,976	7,727	2,197	5,373	2,847	407
Canada ¹	—	—	—	12	6	4
Gabon ²	150,059	74,766	20,928	174,920	88,182	29,801
Mexico	—	—	—	3,268	1,732	407
Morocco	39	20	11	96	49	25
Norway ⁴	25,822	14,242	3,553	17,992	9,780	2,911
Total⁶	260,880	132,628	35,890	237,997	120,769	38,174
FERROMANGANESE						
All grades						
Australia	16,295	12,355	5,049	10,362	7,608	3,510
Brazil	26,328	20,167	13,766	35,890	27,601	16,817
Canada	16,102	12,638	7,263	12,263	9,474	4,773
China	10,113	7,909	6,058	4,983	3,790	2,366
France	⁷ 113,724	⁷ 89,553	⁷ 64,876	91,607	72,084	52,617
Germany, Federal Republic of	19,321	16,174	16,501	20,033	15,960	15,183
Mexico	49,472	39,412	31,665	45,524	36,231	27,439
Norway	8,169	6,789	7,103	13,628	10,836	6,725
Philippines	—	—	—	6,230	4,799	2,721
South Africa, Republic of	144,300	112,015	73,708	89,362	69,903	44,850
United Kingdom	3,286	2,419	815	16,731	12,935	6,980
Other	⁸ 11,580	⁸ 9,919	⁸ 7,528	5,886	4,879	5,181
Total⁶	418,688	328,352	234,329	352,498	276,099	189,162

See footnotes at end of table.

TABLE 10—Continued
**U.S. IMPORTS FOR CONSUMPTION OF MANGANESE ORE, FERROALLOYS,
METAL, AND SELECTED CHEMICALS, BY COUNTRY**

Country	1990			1991		
	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)
FERROMANGANESE—Continued						
1 % or less carbon						
France	8,547	7,634	\$11,674	12,539	11,163	\$16,166
Italy	836	745	1,140	1,042	927	1,393
Japan	624	567	842	1,346	1,224	1,782
Norway	2,171	1,801	2,046	48	42	68
Other	566	465	371	—	—	—
Total^c	12,744	11,212	16,073	14,974	13,356	19,409
More than 1 % to 2 % or less carbon						
Brazil	3,638	2,910	2,778	—	—	—
China	3,629	2,948	2,762	—	—	—
France	2,800	2,252	2,187	2,116	1,680	1,287
Germany, Federal Republic of	19,306	16,162	16,485	20,033	15,960	15,183
Mexico	27,701	22,307	21,232	20,779	16,767	15,700
Norway	5,997	4,988	5,057	9,712	7,749	5,202
South Africa, Republic of	3,069	2,465	2,582	6,485	5,223	5,114
Other	2,755	2,094	2,142	1,552	1,290	1,116
Total^c	68,895	56,126	55,225	60,677	48,669	43,602
More than 2 % to 4 % or less carbon						
Canada	112	88	44	—	—	—
More than 4 % carbon						
Australia	16,295	12,355	5,049	10,362	7,608	3,510
Brazil	22,690	17,257	10,988	35,890	27,601	16,817
Canada	15,990	12,550	7,219	12,226	9,447	4,763
China	5,933	4,509	2,940	4,983	3,790	2,366
France	102,377	79,667	51,015	76,952	59,241	35,164
Mexico	21,771	17,105	10,433	24,745	19,464	11,739
Philippines	—	—	—	6,230	4,799	2,721
South Africa, Republic of	141,231	109,550	71,126	82,877	64,680	39,736
United Kingdom	3,286	2,419	815	16,731	12,935	6,980
Other	7,364	5,514	3,402	5,851	4,509	2,355
Total^c	336,937	260,926	162,987	276,847	214,074	126,151
SILICOMANGANESE						
Argentina	12,013	7,901	5,417	9,012	5,858	3,721
Australia	44,815	29,552	19,004	41,024	26,938	17,159
Brazil	24,554	16,059	11,051	54,416	35,438	23,498
Canada	8,208	5,566	4,099	17,286	11,584	7,616
France	10,846	7,230	5,318	10,955	7,322	5,543
Mexico	42,691	28,110	19,651	25,303	16,592	11,770
Norway	10,347	6,692	6,800	17,343	11,259	9,942
South Africa, Republic of	56,204	37,335	27,664	68,485	45,514	32,088

See footnotes at end of table.

TABLE 10—Continued
**U.S. IMPORTS FOR CONSUMPTION OF MANGANESE ORE, FERROALLOYS,
 METAL, AND SELECTED CHEMICALS, BY COUNTRY**

Country	1990			1991		
	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)
SILICOMANGANESE—Continued						
Yugoslavia	24,493	⁷ 16,013	\$11,115	25,221	16,364	\$11,343
Other	⁸ 13,268	⁸ 8,617	⁸ 7,728	15,674	10,286	7,997
Total ⁶	247,439	163,075	117,847	284,719	187,155	130,677
METAL						
Unwrought:						
China	280	XX	291	1,099	XX	1,298
South Africa, Republic of	10,073	XX	13,852	9,517	XX	13,585
Other	110	XX	265	2	XX	4
Total ⁶	10,463	XX	14,407	10,618	XX	14,887
Other:						
South Africa, Republic of	3,643	XX	4,585	6,513	XX	9,007
Other	170	XX	746	164	XX	558
Total ⁶	3,815	XX	5,331	6,677	XX	9,565
Waste and scrap:						
Canada	1	XX	3	68	XX	7
Venezuela	—	XX	—	44	XX	50
MANGANESE DIOXIDE						
Australia	—	XX	—	9,276	XX	12,255
Belgium	1,200	XX	1,629	1,593	XX	2,238
Brazil	1,707	XX	2,018	1,809	XX	2,242
Ireland	1,349	XX	1,733	6,931	XX	9,013
South Africa, Republic of	3,081	XX	3,862	2,156	XX	2,700
Other	349	XX	635	297	XX	727
Total ⁶	7,687	XX	9,877	22,064	XX	29,174
POTASSIUM PERMANGANATE						
China	1,262	XX	1,182	412	XX	348
Germany, Federal Republic of ⁹	382	XX	366	301	XX	451
Spain	447	XX	812	199	XX	388
Other	28	XX	216	162	XX	363
Total ⁶	2,119	XX	2,576	1,074	XX	1,550

XX Not applicable.

¹Country of transshipment rather than original source.

²Includes quantities believed transhipped to Mexico, about 51,000 tons in 1990 and 27,000 tons in 1991.

³Includes U.S. Bureau of Mines revision of part of reported data.

⁴Data corrected by the U.S. Bureau of Mines.

⁵Includes U.S. Bureau of Mines conversion of part of reported data (from apparent MnO₂ content to Mn content).

⁶Data may not add to totals shown because of independent rounding.

⁷Data corrected by the Bureau of the Census.

⁸Unspecified group of countries differs from that in the 1990 Minerals Yearbook.

⁹Data for Jan.-Sept. 1990 originally listed under Federal Republic of Germany: Eastern States.

Source: Bureau of the Census, adjusted by the U.S. Bureau of Mines.

TABLE 11
U.S. IMPORT DUTIES ON MANGANESE MATERIALS¹

Item	HTS No.	Rate of duty effective Jan. 1, 1991	
		Most favored nation (MFN)	Non-MFN
Ore and concentrate	2602.00.00	Free	1 cent per pound Mn.
Manganese dioxide	2820.10.00	4.7% ad valorem ^{2 3 4}	25% ad valorem.
Ferromanganese:			
Low-carbon	7202.19.10	2.3% ad valorem ^{2 3 5}	22% ad valorem.
Medium-carbon, 1% to 2% carbon	7202.19.50	1.4% ad valorem ^{2 3 5 6}	6.5% ad valorem.
High-carbon	7202.11.50	1.5% ad valorem ^{2 5}	10.5% ad valorem.
Silicomanganese	7202.30.00	3.9% ad valorem ^{2 3 5 7}	23% ad valorem.
Metal, unwrought	8111.00.45	14% ad valorem ^{2 8}	20% ad valorem.

¹All subject to (1) 0.17% ad valorem Merchandise Processing Fee except for products from beneficiary countries under the Caribbean Basin Economy Recovery Act (CBERA) and least-developed developing countries and (2) 0.125% ad valorem Harbor Maintenance Fee for cargo unloaded from waterborne vessels at U.S. ports open to public navigation.

²Free from beneficiary countries under CBERA and for products of Israel.

³Free from certain countries under Generalized System of Preferences.

⁴1.8% ad valorem for products of Canada.

⁵Free for products of Canada.

⁶Not duty free for Mexico.

⁷Not duty free for Brazil.

⁸9.8% ad valorem for products of Canada.

TABLE 12
WORLD ANNUAL MANGANESE
MINE PRODUCTION CAPACITY,
DECEMBER 31, 1991

(Thousand short tons of manganese content)

Country	Rated capacity
North America:	
Mexico	230
United States	—
Total	230
South America:	
Brazil	1,100
Chile	20
Total	1,120
Europe:	
Bulgaria	15
Hungary	30
U.S.S.R.	3,300
Other	40
Total	3,385
Africa:	
Gabon	1,350
Ghana	150
Morocco	30
South Africa, Republic of	2,500
Total	4,030
Asia:	
China	600
India	600
Other	15
Total	1,215
Oceania:	
Australia	1,350
World total (rounded)	11,300

**TABLE 13
WORLD MANGANESE
RESERVES
AND RESERVE BASE**

(Million short tons of manganese content)

Country	Reserves	Reserve base
North America:		
Mexico	4	10
South America:		
Brazil	23	65
Europe: U.S.S.R.	325	500
Africa:		
Gabon	58	180
Ghana	1	5
South Africa, Republic of	407	4,400
Total	466	4,585
Asia:		
China	15	32
India	19	28
Total	34	60
Oceania: Australia	30	80
World total (rounded)	880	5,300

**TABLE 14
SOUTH AFRICAN MANGANESE
ORE PRODUCTION, 1991**

(Thousand short tons, gross weight)

Grade	Quantity
METALLURGICAL ORE	
30% to 40% Mn	719
Over 40% to 45% Mn	693
Over 45% to 48% Mn	200
Over 48% Mn	1,804
Total¹	3,416
CHEMICAL ORE	
35% MnO ₂ and less	—
Over 35% to 65% MnO ₂	49
Over 65% to 75% MnO ₂	(²)
Total¹	50

¹Data may not add to totals shown because of independent rounding.

²Less than 1/2 unit.

TABLE 15
MANGANESE ORE: WORLD PRODUCTION, BY COUNTRY¹

(Thousand short tons)

Country ²	Range percent Mn ³	Gross weight					Metal content				
		1987	1988	1989	1990	1991 ⁴	1987	1988	1989	1990	1991 ⁴
Australia ⁴	37-53	2,043	2,189	2,341	² 2,116	⁵ 1,634	972	¹ 1,041	1,111	¹ 1,002	773
Brazil ^{6 7}	30-50	2,279	2,194	2,293	² 2,756	2,400	842	841	871	¹ 1,047	910
Bulgaria	29-35	42	³ 38	³ 36	² 55	50	12	11	¹ 12	² 18	16
Chile	30-40	35	48	48	44	44	12	16	15	¹ 14	14
China ^{6 8}	20-30	2,900	3,500	³ 3,700	² 3,600	3,700	580	700	² 740	² 720	740
Gabon ^{6 9}	50-53	2,649	2,485	2,858	² 2,671	2,300	1,223	1,147	1,319	¹ 1,233	1,060
Ghana ⁶	30-50	303	286	308	² 272	300	108	106	121	¹ 106	115
Hungary ^{6 10}	30-33	86	89	93	¹ 66	72	28	29	29	² 21	22
India ^{6 9 11}	10-54	1,435	1,469	1,471	¹ 1,502	1,400	534	547	548	⁵ 564	530
Iran ⁶	25-35	¹ 69	² 82	² 89	¹ 60	72	² 22	² 25	² 26	¹ 18	22
Mexico ¹²	27-50	⁴ 25	⁴ 89	⁴ 35	² 403	200	161	186	165	¹ 153	76
Morocco ⁶	50-53	47	33	35	¹ 54	65	25	18	19	² 29	34
Romania ^{6 10}	30	72	72	66	¹ 61	55	21	21	20	19	17
South Africa, Republic of ^{6 9}	30-48+	³ 3,631	⁴ 4,34	⁵ 3,84	⁴ 4,852	³ 3,465	¹ 1,520	¹ 1,825	² 2,253	² 2,107	1,508
U.S.S.R.	29-30	¹ 10,313	¹ 10,040	¹ 10,076	² 9,400	8,800	3,100	³ 3,000	² 3,020	² 2,800	2,600
Yugoslavia	25-45	46	44	43	¹ 56	44	16	¹ 15	15	² 20	15
Other ¹³	XX	² 29	⁵ 0	¹ 47	¹ 68	65	¹ 12	² 20	² 20	³ 30	28
Total	XX	² 26,404	² 27,542	² 29,323	² 28,036	24,666	² 9,188	² 9,548	¹ 10,304	² 9,901	8,480

¹Estimated. ²Revised. XX Not applicable.

³Table includes data available through May 11, 1992. Data pertain to concentrates or comparable shipping product, except that in a few instances the best data available appear to be for crude ore, possibly after some upgrading.

⁴In addition to the countries listed, Colombia, Cuba, Panama, Peru, and Sudan may have produced manganese ore and/or manganiferous ore, but available information is inadequate to make reliable estimates of output levels. Low-grade ore not included in this table has been reported as follows, in thousand short tons, gross weight: Argentina (19% to 30% Mn) 1987-7, 1988-10, 1989-6, 1990-6 (estimated), and 1991-6 (estimated); and Czechoslovakia (about 17% Mn), an estimated 1 in each year.

⁵May be for average content of each year's production rather than for content of typical products.

⁶Metallurgical ore.

⁷Reported figure.

⁸Gross weight reported; metal content estimated.

⁹Reported gross-weight figures are the sum of (1) sales of direct-shipping manganese ore and (2) production of beneficiated ore, both as reported in Anuário Mineral Brasileiro.

¹⁰Includes manganiferous ore.

¹¹Calculated metal content includes allowance for assumed moisture content.

¹²Concentrate.

¹³Much of India's production grades below 35% Mn; average content was reported as 38% Mn in 1985.

¹⁴Estimated product total, mostly oxide nodules; may include smaller quantities of direct-shipping carbonate and oxide ores for metallurgical and battery applications.

¹⁵Category represents the combined totals of Greece, Indonesia, Italy (from wastes), Japan, the Republic of Korea, Pakistan, the Philippines, Thailand, Turkey, and Zambia.

TABLE 16
MANGANESE SUPPLY-DEMAND RELATIONSHIPS¹

(Thousand short tons, manganese content)

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mines ²	23	24	4	4	11	2	1	2	1	1	1
Shipments of Government stockpile excesses	159	128	28	35	10	91	8	105	(2)	(6)	22
Imports, ore and dioxide ¹	330	301	111	178	180	204	237	181	262	303	169
Imports, ferroalloy and metal	530	615	430	364	426	405	452	422	581	553	505
Industry stocks, Jan. 1	749	710	702	576	463	420	380	315	279	316	324
Total U.S. supply	1,791	1,778	1,275	1,157	1,090	1,122	1,078	1,025	1,121	1,167	1,021
Distribution of U.S. supply:											
Industry stocks, Dec. 31	710	702	576	462	420	380	315	279	316	324	266
Exports, ore	26	32	14	10	30	31	23	38	35	29	46
Exports, ferroalloy and metal	26	17	13	17	13	13	10	9	18	17	14
Industrial demand	1,029	1,027	672	668	627	698	730	699	752	797	695
U.S. DEMAND PATTERN³											
Appliances and equipment	49	51	30	33	36	32	27	31	19	12	10
Batteries	17	16	21	25	34	39	43	43	48	45	46
Cans and containers	49	46	31	28	38	35	31	35	31	23	24
Chemicals ⁴	50	50	29	22	34	22	23	44	46	43	40
Construction	243	252	152	151	170	164	148	165	244	152	152
Machinery	167	171	92	90	97	78	65	77	110	83	82
Oil and gas industries	79	89	40	28	36	34	25	30	21	10	15
Transportation	214	214	115	129	139	124	95	105	102	54	50
Other ⁵	161	138	162	162	43	170	273	169	131	375	276
Total U.S. primary demand	1,029	1,027	672	668	627	698	730	699	752	797	695

¹Where available, data for manganese dioxide included beginning in 1984.

²Including manganiferous ore.

³New series for steel-related end uses beginning in 1989.

⁴Includes miscellaneous nonmetallurgical uses of ore beginning in 1987.

⁵Not specifically based on reported data; includes processing losses. Through 1988, the distribution within this category is approximately the same as for end uses above. Beginning in 1989, includes nonidentified uses of steel corresponding to about one-third of total steel shipments.

MERCURY

By Robert G. Reese, Jr.

Mr. Reese, a physical scientist with the Branch of Metals, has been the commodity specialist for mercury for 4 years. Domestic survey data were prepared by Kevin Bacon, mineral data assistant; and the international data table was prepared by William Zajac, Chief, International Data Section.

The mercury market continued to shrink in 1991. Major factors in the lower consumption included the availability and development of substitutes and mercury's potential to be a health hazard and environmental pollutant. In 1991, the United States produced mercury only as a byproduct of gold mining. Worldwide, mine production declined in response to lower prices and demand.

ANNUAL REVIEW

Production

The primary mine production data contained in the accompanying tables were the quantity of mercury produced at the McDermitt Mine as reported in Placer Dome Inc.'s annual and 10K reports. The McDermitt Mine, closed in late 1990, remained idle through yearend 1991. Reportedly though, the company continued to sell mercury from the mine's stocks.

According to the Bureau's voluntary survey, eight gold mines in California, Nevada, and Utah recovered byproduct mercury. The mines in Nevada accounted for almost all of the byproduct production shown in table 1. The Paradise Peak Mine in Nevada was the largest byproduct mercury producer.

Consumption and Uses

Industrial consumption of refined mercury metal plummeted for the third consecutive year. Product evolution and environmental concern continued to depress mercury consumption by the battery industry. Changing technology

has reduced the mercury content of some batteries by as much as 98%. Also, mercury-free batteries such as the zinc-air cell continued to replace mercury-bearing batteries in some applications. The drop in consumption by the chlorine and caustic soda industry was attributable to the closure of several mercury-cell plants. In other applications, the most significant factor affecting demand was probably the general economic recession, although the mercury content of the final product was a concern to many manufacturers.

Stocks

Stocks of refined mercury held by consumers and dealers declined by almost 22% in 1991 and, at yearend, were equivalent to about 3 months industrial consumption. Data on stocks held at mines were withheld to avoid disclosing company proprietary data. The Department of Energy (DOE) held an inventory of used (scrap) mercury at Oak Ridge, TN. The Government classified all this material as excess to its needs. The Defense Logistics Agency (DLA), acting as DOE's agent, offered limited quantities of the material for sale at monthly auctions. DLA shipped 215 metric tons during the year, leaving yearend stocks at 224 tons.

At yearend 1990, the National Defense Stockpile contained 5,459 tons of mercury. During 1991, the goal for the stockpile was 362 tons. The remaining 5,097 tons was regarded as excess to Government needs. DLA, acting as the Government's sales agent, sold 129 tons of the excess mercury, leaving 5,330 tons in the stockpile at yearend.

Markets and Prices

The New York dealer price for delivered primary mercury, reported in Metals Week as a range, declined throughout most of the year. The price at the low end of the range began the year at \$180 per flask. From this peak, the low-end price declined steadily until the beginning of September when it reached \$85 per flask, its low for the year. The price remained at \$85 per flask until the end of October. During the final 2 months of 1991, the price increased, reaching \$155 by yearend. The price at the high end of the range tracked the movement of the low end price closely, but was \$5 to \$15 per flask higher.

Analysts attributed the price movement to supply-demand fundamentals. Globally, declining demand combined with abundant supplies resulted in falling prices during most of the year. As the prices dropped, some suppliers reportedly reduced their operations. As supplies tightened toward yearend, consumers and dealers bid up the mercury price to obtain the mercury needed to meet their commitments. The annual average of the weekly low end price was \$122.42 compared with \$249.22 in 1990.

World Review

World mercury demand, especially in industrialized countries, probably declined. Although there were no supporting data, media articles continued to show other countries' concern about potential mercury contamination.

At least 11 countries produced mercury in 1991. Several mercury mines curtailed

operations in response to the perceived drop in demand. According to media reports, a Chinese mine closed, and the Almaden Mine in Spain reduced its production significantly.

OUTLOOK

The outlook for the mercury market remains as it has for the past several years. Enactment of additional regulations restricting the use of mercury is likely. When combined with the lack of new major uses for the metal, mercury demand should continue to decline. With reduced operations at many producers, the U.S. Government may have an opportunity to further reduce its large mercury holdings.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Mercury. Ch. in Mineral Commodity Summaries, annual.

Other Sources

American Metal Market.
Engineering and Mining Journal.
London Metal Bulletin.
Metals Week.

TABLE 1
SALIENT MERCURY STATISTICS

		1987	1988	1989	1990	1991
United States:						
Producing mines		9	10	10	9	8
Mine production ¹	metric tons	34	379	414	NA	NA
Byproduct production	do.	W	W	W	114	58
Secondary production:						
Industrial	do.	265	278	137	93	122
Government ²	do.	117	214	180	193	215
Industry stocks, yearend ³	do.	320	338	217	202	157
Shipments from the National Defense Stockpile⁴						
Imports for consumption	do.	636	329	131	15	56
Exports	do.	NA	NA	221	311	786
Industrial demand	do.	1,446	1,593	1,214	720	473
Price: New York, average per flask		\$295.50	\$335.52	\$287.72	\$249.22	\$122.42
Employment, mine and mill, average		9	12	25	21	3
World: Mine production	metric tons	5,534	*6,835	*6,749	*5,061	*4,536

*Estimated. †Revised. NA Not available. W Withheld to avoid disclosing company proprietary data.

¹Comprises only the mercury produced at the McDermitt Mine, as reported in Placer Dome Inc. annual and 10-K reports.

²Secondary mercury shipped from U.S. Department of Energy stocks.

³Stocks at consumers and dealers only. Mine stocks withheld to avoid disclosing company proprietary data.

⁴Primary mercury.

TABLE 2
BYPRODUCT MERCURY-
PRODUCING MINES IN THE
UNITED STATES IN 1991

Mine	County and State	Operator
Carlin Mines Complex	Eureka, NV	Newmont Gold Co.
Hog Ranch	Washoe, NV	Western Hog Ranch Co.
Enfield Bell	Elko, NV	Independence Mining Co. Inc.
Getchell	Humboldt, NV	FMC Gold Co.
McLaughlin	Napa, CA	Homestake Mining Co.
Mercur	Tooele, UT	Barrick Mercur Gold Mines Inc.
Paradise Peak	Nye, NV	FMC Gold Co.
Pinson and Kramer Hill	Humboldt, NV	Pinson Mining Co.

TABLE 3
U. S. INDUSTRIAL CONSUMPTION OF REFINED MERCURY METAL,
BY USE¹

(Metric tons)

SIC code	Use	1987	1988	1989	1990	1991
28	Chemical and allied products:					
2812	Chlorine and caustic soda manufacture	311	445	381	247	184
2819	Laboratory uses	20	26	18	32	10
2851	Paint	198	197	192	22	6
—	Other chemical and allied products ²	59	86	40	33	18
36	Electrical and electronic uses:					
3641	Electric lighting	45	31	31	33	29
3643	Wiring devices and switches	131	176	141	70	25
3692	Batteries	533	448	250	106	78
38	Instruments and related products:					
382	Measuring and control instruments	59	77	87	108	70
3843	Dental equipment and supplies	56	53	39	44	27
—	Other uses ³	34	55	35	25	26
	Total⁴	1,446	1,593	1,214	720	473

¹The input of refined liquid mercury to domestic manufacturing establishments.

²Pigments, pharmaceuticals, catalysts for plastics, and miscellaneous catalysts, shown as separate items in previous editions of this table, have been included in this category.

³Other electrical and electronic uses, other instruments and related products, shown as separate items in previous editions of this table, have been included in this category.

⁴Data may not add to totals shown because of independent rounding.

TABLE 4
AVERAGE PRICE OF MERCURY
AT NEW YORK

(Per flask)

Period	Price
1987	\$295.50
1988	335.52
1989	287.72
1990	249.22
1991:	
January	177.14
February	158.95
March	142.86
April	122.27
May	115.00
June	111.25
July	100.90
August	97.73
September	85.00
October	90.91
November	119.21
December	147.86
Average	122.42

Source: Metals Week.

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF MERCURY AND
MERCURY-BEARING WASTE AND SCRAP, BY COUNTRY

Country	1989		1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	2	\$13	—	—	—	—
Canada	—	—	9	\$72	51	\$150
China	—	—	—	—	1	2
Germany, Federal Republic of	1	51	6	122	3	133
Netherlands	1	9	—	—	—	—
Spain	127	1,137	1	12	(¹)	5
United Kingdom	—	—	—	—	1	4
Other	(¹)	37	(¹)	26	(¹)	7
Total ²	131	1,247	15	231	56	301

¹Less than 1/2 unit.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 6
U.S. EXPORTS OF MERCURY, BY COUNTRY

Country	1989		1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Argentina	—	—	—	—	3	\$9
Australia	8	\$72	4	\$32	5	20
Brazil	10	308	34	489	7	47
Canada	11	64	38	335	11	88
Colombia	3	42	26	118	16	42
Ecuador	—	—	3	30	—	—
France	—	—	—	—	182	1,383
Germany, Federal Republic of	37	19	2	46	(¹)	9
Hong Kong	—	—	4	15	69	138
India	9	287	76	534	115	363
Ireland	4	36	4	30	9	63
Japan	—	—	—	—	21	35
Korea, Republic of	1	22	2	25	10	36
Mexico	1	7	1	35	31	83
Netherlands	82	512	108	529	264	541
Peru	1	14	2	15	—	—
Singapore	2	22	—	—	—	—
South Africa, Republic of	44	269	—	—	7	22
Spain	—	—	—	—	18	37
Taiwan	2	90	—	—	4	67
United Kingdom	2	24	—	—	2	14
Venezuela	3	39	3	32	10	51
Other	1	47	4	175	2	96
Total	221	1,874	311	2,440	786	3,144

¹Revised.

¹Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 7
MERCURY: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country	1987	1988	1989	1990	1991*
Algeria	705	690	586	¹ 637	² 650
China ³	700	⁴ 940	⁵ 880	⁶ 800	700
Czechoslovakia	164	168	131	¹ 126	120
Dominican Republic	(⁷)	(⁸)	(⁹)	¹ (⁰)	—
Finland	144	130	159	¹ 141	125
Mexico	124	345	¹ 651	¹ 735	² 720
Spain	1,085	1,716	¹ 1,380	¹ 425	450
Turkey	211	97	197	¹ 60	60
U.S.S.R. ³	2,300	2,300	2,300	2,100	1,900
United States ⁵	34	379	414	NA	NA
Yugoslavia	67	70	51	¹ 37	30
Total	5,534	¹ 6,835	¹ 6,749	¹ 5,061	4,755

*Estimated. ¹Revised. NA Not available.

¹Table includes data available through May 20, 1992.

²Less than 1/2 unit.

³Revised to zero.

⁴Reported figure.

⁵Comprises only the mercury produced at the McDermitt Mine, as reported in Placer Dome Inc. Annual and 10-K reports.

MICA

By Lawrence L. Davis

Mr. Davis, a physical scientist with 36 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for mica since 1983. Domestic survey data were prepared by Linder Roberts, statistical assistant; and international data tables were prepared by Audrey Wilkes, international data coordinator.

Public Law 100-418 requires that U.S. Government agencies implement the use of metric units in their business activities by the end of fiscal year 1992. Consequently, all numbers in the text and tables are shown in metric units.

In 1991, about 103,000 metric tons of scrap and flake mica was produced in the United States, a decrease of 5% from 1990 production. Ground mica sales were 75,000 tons valued at \$17 million, a decrease in tonnage of about 23%.

Almost all sheet mica supply continued to be imported. Consumption of muscovite block mica decreased slightly to 5.9 tons. Consumption of mica splittings increased slightly to 854 tons. The value of sheet mica remained at \$7.8 million. The value of imports for consumption of sheet mica decreased 12% to \$8.4 million. (See table 1.)

DOMESTIC DATA COVERAGE

Domestic production and consumption data for mica are developed by the U.S. Bureau of Mines by means of three separate, voluntary surveys and one mandatory survey. Of the 18 operations to which the crude scrap and flake mica production form was sent, 15 operations, or 83%, responded, representing 87% of the production shown in table 1. Of the 17 operations to which the ground mica form was sent, 14 responded, representing 85% of the production in table 1. Of the five canvassed operations to which the mica block and film consumption form was sent, three, or 60%, responded, representing 72% of the consumption shown in table 1. Of the nine canvassed operations to which the mica splittings consumption form was

sent, seven operations, or 78%, responded, representing more than 98% of the splittings consumption shown in table 1. Consumption for the nonrespondents was estimated using prior-year production data.

BACKGROUND

Definitions, Grades, and Specifications

Mica is a group name for a number of complex hydrous potassium silicate minerals with differing chemical compositions and physical properties. Crystals of mica have excellent basal cleavage and split easily into tough, flexible sheets. The important mica minerals are muscovite and phlogopite.

Commercial qualities of sheet mica are relatively free of defects and tough enough to be punched or stamped into specific shapes. Sheet mica is classified as block, film, or splittings. Block mica is not less than 0.018 centimeters thick and has a minimum usable area of 2.54 square centimeters. Film mica is split to specified thicknesses ranging from 0.0030 to 0.010 centimeters. Splittings are sheets with a maximum thickness of 0.0030 centimeters and a minimum usable area of 1.9 square centimeters. Punch mica, which includes circle and washer mica, is low-quality, hand-trimmed mica up to about 5 centimeters in diameter. The American Society for Testing and Materials (ASTM) designates 13 quality groups for sheet mica, based on quantity of visible inclusions and structural imperfections, ranging from black- and red-stained to perfectly clear. ASTM also designates 12 grades based on the maximum usable rectangle. The sizes

range from grade 6 (with 2.54 usable square centimeters) to grade OOOE special (with 254 usable square centimeters).¹

Block and film mica products are small flat pieces of uniformly thin mica cut or stamped to close tolerances into a variety of shapes and sizes, depending on the use. Shapes can vary from simple circles, squares, or rectangles to very intricate patterns. Fabricators make their own dies to be able to cut the mica into any pattern desired.

Built-up mica, or micanite, consists of partly overlapped and irregularly shaped and arranged splittings cemented together with either an organic or inorganic binder. Large sheets of built-up mica are made by alternating layers of splittings and binder. Sheets of any thickness are made by pressing the layers at high temperatures. Built-up mica is sold in large, uncut sheets or is cut or molded to any size and shape specified by the customer. It is often bonded to another material such as fiberglass cloth to form a composite sheet.

Reconstituted mica or mica paper is a paperlike material made by depositing fine flakes of scrap mica as a continuous mat, which is then dried. The mica paper is sometimes impregnated with an organic binder.

Scrap and flake mica is generally of a quality and size that is not suitable for use as sheet mica. Mine scrap varies greatly in quality but usually is a heterogeneous mixture that must be crushed, screened, and washed to yield the scrap mica in usable form. Mine scrap may be the sole product of mining a pegmatite or may be a byproduct of sheet mica production. Bench scrap or

shop scrap is the mica discarded during the processing of handcobbed mica into sheet. Factory scrap is the waste that results from cutting and stamping sheet mica into pieces of definite size and shape. Factory scrap is usually the highest grade and quality material. Scrap mica that is recovered from schists and from the beneficiation of feldspar, kaolin, and lithium pegmatites is often referred to as flake.²

Industry Structure

The sheet mica industry in the United States is small, consisting of processors and fabricators of imported mica. Worldwide, India dominates the production of muscovite sheet mica. Madagascar is an important producer of phlogopite sheet mica. Sheet mica mining, trimming, and splitting are very labor intensive, and producing countries have the advantage of low wages and a large labor force that is usually trained at an early age. India's sheet mica industry is characterized by a large number of small operations, most of which sell to larger companies or the Government's Mica Trading Corp. of India Ltd. for further processing and export. India is putting more emphasis on exporting fabricated mica products. This is expected to reduce further the amount of mica that will be fabricated in the United States.

The U.S. flake mica industry ranks first in world production. Most production comes from surface mining of mica schists and as a byproduct of feldspar, kaolin, and lithium beneficiation. Nearly all flake mica is ground to final specifications depending on the use. Other countries producing significant amounts of flake mica are Canada, China, India, the Republic of Korea, and the U.S.S.R. Many other countries produce small amounts.

Geology-Resources

Sheet muscovite is obtained from coarse-grained igneous rocks called pegmatites. Pegmatites also contain

feldspar, quartz, and various accessory minerals. Pegmatite dikes and veins range from 1 kilometer or more long and 100 meters wide to thin veins and veinlets of approximately 2 centimeters in width.

The United States has no reserves of sheet mica. Small U.S. reserves were extensively worked in the past, and the high cost of labor has kept the mines shut down since the Government's purchase program ended in 1962. The primary sheet mica resources are in New England, the southeastern Piedmont from Virginia to Alabama, the Blue Ridge Mountains in North Carolina, the Black Hills of South Dakota, and northern New Mexico. Other States with some sheet mica resources are California, Colorado, Idaho, Montana, and Wyoming.

No formal evaluation of world resources of sheet mica has been made, mainly because of the sporadic occurrence of this mineral. The most productive sheet mica districts in the world are in the States of Bihar, Andhra Pradesh, and Rajasthan in India. India's large reserves and resources of sheet mica have been the primary world sources for many years. Large reserves of sheet mica also are found in Brazil and western Africa. In the U.S.S.R., sheet mica reserves are known in the Lake Baikal and Sayan upland areas as well as in the South Eniessy Range. Smaller but substantial reserves occur in Argentina, Australia, and Zimbabwe.

Phlogopite deposits are in areas of metamorphosed sedimentary rocks intruded by masses of pegmatite-rich granitic rocks. The phlogopite is found as veins or pockets in pyroxenite interlayered with or intersecting marble or gneiss. Canada and Madagascar have the world's major reserves of phlogopite. Additional reserves are known in Mexico, Sri Lanka, and the Sludyanka River district and Alden area of the U.S.S.R.

The primary domestic source of flake mica for grinding purposes is weathered alaskite bodies and pegmatites in North Carolina, where most domestic flake mica is produced. The mica is recovered as a coproduct of feldspar and kaolin beneficiation. Flake mica is also recovered from muscovite schists. These

schists bodies range in size from 3 to more than 100 meters thick and several kilometers long. The mica content ranges up to 90%. Another form of flake mica is fine-grained muscovite called sericite, which is an alteration product of various aluminosilicate minerals.

World reserves and resources of scrap and flake mica are not well known but are considered to be very large. All countries with sheet mica reserves or resources have even larger quantities of scrap mica because only a small fraction of the mica present is of sheet quality. Many other countries have reserves or resources of mica that, while not of sheet quality, are suitable for grinding.

ANNUAL REVIEW

Legislation and Government Programs

The Government inventory of stockpile-grade mica remained about the same at 10,000 tons. The U.S. Department of Defense sold 2 tons of muscovite block, stained and better. (See table 2.)

Strategic Considerations

Sheet mica and high-quality scrap mica used for making mica paper are important in the electronic and electrical industries. The United States is not self-sufficient in these materials and imports all its supplies, mostly from India. The U.S.S.R. and other Eastern European countries are currently India's largest customers. The United States and other market economy countries compete for the remaining mica, and availability is sometimes limited, particularly for high-quality mica. Long delivery times and quality inconsistency also adversely affect sheet mica availability.

In a short-supply situation during an emergency, the National Defense Stockpile would be able to meet short-term demand until substitutes could be made available. It is unlikely that domestic sheet mica production could replace or significantly reduce imports. Of the five strategic stockpile categories, only muscovite block mica has ever been

produced domestically in significant quantities, and then only under the stimulus of above-market prices paid by the Government. Domestic production in this century never provided more than a small fraction of domestic requirements.

The domestic supply of flake mica is adequate. Scrap and flake mica are not considered to be strategic materials. The United States is self-sufficient in flake mica but does rely on imports of high-quality scrap for the manufacture of mica paper.

Production

Scrap and Flake Mica.—North Carolina remained the major producing State, with 62% of the total production. The remainder was produced in California, Connecticut, Georgia, New Mexico, Pennsylvania, South Carolina, and South Dakota. Most mica was recovered from mica schist, high-quality sericite schist, and as a byproduct of feldspar, kaolin, and lithium beneficiation.³ The five largest producers were, in alphabetical order, The Feldspar Corp., Spruce Pine, NC; KMG Minerals Inc., Kings Mountain, NC; Lithium Corp. of America, Gastonia, NC; Pacer Corp., Custer, SD; and Unimin Corp., Spruce Pine, NC. These five companies produced 61% of the national total.

Cyprus Foote Mineral Co. closed its mine at Kings Mountain, NC, in December. The closure was expected to be permanent. A new mica producer, Rednour Mining Corp., was engaged in preparatory work on its Twin Mountain Mine at King Mountain, NC. Production was to begin in early 1992.

Low-quality sericite, used primarily in brick manufacturing, is excluded from tabulated data contained in this report. In 1991, four companies, one in North Carolina and three in South Carolina, mined 11,000 tons of low-quality sericite and reported an average value of \$4.67 per ton.

Ground Mica.—Twelve companies operated 15 grinding plants in 7 States. Ten plants produced dry-ground and five

produced wet-ground mica. The dry-ground mica plant of Deneen Mica Co., Micaville, NC, was inactive during the year. The five largest producers accounted for 75% of the total. They were, in alphabetical order, KMG Minerals, Kings Mountain, NC; MICA-A Franklin Limestone Co., Fairview, NM; Mineral Mining Co., Kershaw, SC; Unimin, Spruce Pine, NC; and USG Corp., Spruce Pine, NC.

J. M. Huber was trying to sell its mica operations at Kings Mountain and Spruce Pine, NC. At yearend, the facilities were still for sale. (See tables 3 and 4.)

Consumption and Uses

Sheet Mica.—Sheet mica is used principally in the electronic and electrical industries. Its usefulness in these applications stems from its unique electrical and thermal insulating properties and its mechanical properties, which allow it to be cut, punched, or stamped to close tolerances.

The largest use of block mica is as an electrical insulator in electronic equipment. High-quality block mica is also used to line the gauge glasses of high-pressure steam boilers. Transparency, flexibility, and resistance to heat and chemical attack are the properties that make mica suitable for this use. Other uses include diaphragms for oxygen-breathing equipment, marker dials for navigation compasses, optical filters, retardation plates in helium-neon lasers, pyrometers, thermal regulators, and stove windows.

Muscovite film mica is used as a dielectric in capacitors. Only high-quality mica, at or near the top of the quality scale, is used. The highest quality goes into capacitors that are to be used as standards. The next highest qualities are used for transmitting capacitors. Receiving capacitors use slightly lower quality film.

Consumption of muscovite block (ruby and nonruby) totaled 5.9 tons, a slight decrease from that of 1990. Stained and lower-than-stained quality remained in greatest demand accounting for 86% of consumption. About two-thirds of the

muscovite consumed was grade No. 4 or larger. The decrease in consumption was a continuation of a long-term decrease in block mica use. Five companies continued to consume muscovite block and film in five plants in four States: two in North Carolina and one each in New Jersey, Ohio, and Virginia.

Splittings represent the largest part of the sheet mica industry in the United States. Muscovite and phlogopite splittings are used to make built-up mica. Consumption of mica splittings increased slightly to 854 tons. Muscovite splittings from India accounted for nearly all of the consumption. The remainder was phlogopite splittings from Madagascar. The splittings were fabricated into various built-up mica products by nine companies operating nine plants in seven States.

Built-up Mica.—The primary use of this mica-base product, made by mechanical or hand setting of overlapping splittings and alternate layers of binders and splittings, was as electrical insulation material. Principal built-up mica products are segment plate, molding plate, flexible plate, heater plate, and tape.

Segment plate acts as insulation between the copper commutator segments of direct-current universal motors and generators. Phlogopite built-up mica is preferred because it will wear at the same rate as the copper segments. Muscovite has a greater resistance to wear, causing uneven ridges that may interfere with the operation of the generator.

Molding plate is sheet from which V-rings are cut and stamped for use in insulating the copper segments from the steel shaft at the ends of a commutator. Molding plate is also fabricated into tubes and rings for insulation in transformers, armatures, and motor starters.

Flexible plate is used in electric motor and generator armatures, field coil insulation, and magnet and commutator core insulation. Heater plate is used where high-temperature insulation is required.

Some types of built-up mica have the bonded splittings reinforced with special paper, silk, linen, muslin, glass cloth, or

plastic. These products are very flexible and are produced in wide, continuous sheets that either are shipped in rolls or cut into ribbons, tapes, or any desired dimensions.

Total production, sold or used, of built-up mica decreased 3% from that of 1990. Molding plates and segment plates were the major end products, accounting, respectively, for 36% and 33% of the total. Other end products included flexible plates, heater plates, and tapes.

Reconstituted Mica (Mica Paper).—

Primary end uses for mica paper are the same as those for built-up mica. Three companies consumed scrap mica to produce mica paper. The principal source of this scrap mica was India. Manufacturing companies in 1991 were Corona Films Inc., West Townsend, MA; General Electric Co., Coshocton, OH; and US Samica Corp., Rutland, VT. (See tables 5, 6, and 7.)

Ground Mica.—The largest domestic use of ground mica was in gypsum plasterboard joint cement. The mica acts as a filler and extender, provides a smooth consistency, improves the workability of the cement, and imparts resistance to cracking.

In the paint industry, ground mica is used as a pigment extender that also facilitates suspension, reduces checking and chalking, prevents shrinking and shearing of the paint film, increases resistance of the paint film to water penetration and weathering, and brightens the tone of colored pigments.

Ground mica is used in the well-drilling industry as an additive to drilling muds. The coarsely ground mica flakes help prevent lost circulation by sealing porous sections of the drill hole.

The rubber industry uses ground mica as an inert filler and as a mold lubricant in the manufacture of molded rubber products such as tires. The plastics industry uses ground mica as an extender and also as a reinforcing agent.

Ground mica is used in the production of rolled roofing and asphalt shingles, where it serves as an inert filler and surface coating to prevent sticking of

adjacent surfaces. The coating is not absorbed by freshly made roofing because mica has a platy structure and is not affected by the acid in the asphalt or by weathering. Other uses include decorative coatings on wallpaper and on concrete, stucco, and tile surfaces; as an ingredient in some special greases; as a coating for cores and molds in metal casting; and as a flux coating on welding rods.

In 1991, the major end uses were joint cement, 52%; paints, 20%; and well-drilling muds, 5%. (See table 8.)

Stocks

Reported yearend consumer stocks of sheet mica increased 4% to 639 tons; of this, mica splittings represented 96%, and mica block represented 4%.

Markets and Prices

Prices for sheet mica vary with grade and quality and can range from less than \$1 per kilogram for low-quality mica to more than \$2,000 per kilogram for the highest quality. The average values of muscovite sheet mica consumed in the United States in 1991 compared with 1990 were as follows: Block decreased 8% to \$85 per kilogram, and splittings decreased slightly to \$1.54 per kilogram. The average value of phlogopite block remained at \$26 per kilogram, while the value of phlogopite splittings decreased slightly to \$4.41 per kilogram. The changes in average value are more a reflection of the quality of mica consumed during the year than actual changes in price. The average value of crude flake mica, including high-quality sericite, was \$54 per ton. The average value per ton for North Carolina flake mica, predominantly a flotation product, was \$59. (See table 9.)

Foreign Trade

The United States continued to rely on imports, mostly from India, for nearly all of its sheet mica and paper-quality scrap mica. Imports for consumption of unmanufactured block, film, and

splittings were about 1,400 tons, 12% less than in 1990. Worked mica imports were about 900 tons, 15% less than in 1990. About 9,700 tons of ground mica was imported mostly from Canada, while about 3,400 tons was exported to 29 countries. The combined value of all mica imports decreased 6% to \$14.7 million, while the combined value of all mica exports decreased 7% to \$9.8 million. (See tables 10, 11, 12, 13, 14, and 15.)

World Review

World production of mica decreased 6% to 198,000 tons. The United States continued to lead in the production of flake mica. India continued to lead in the production of sheet mica.

Wood Treatment Ltd., of the United Kingdom, a ground mica producer, decided to get out of the mica business. Microfine Minerals Ltd. agreed to use Wood Treatment's grinding facilities in Chestire and to fulfill Wood Treatment's existing contracts.⁴ (See table 16.)

OUTLOOK

Demand for sheet mica has decreased dramatically during the past 30 years. For block and film mica, the major cause of decreased demand was technological change, specifically the introduction of semiconductor technology in electronics to the detriment of vacuum tube electronics that used large quantities of mica. Although the major impact of the technology change was felt in the 1960's and 1970's, consumption of block and film mica continues to decrease, albeit more slowly. Substitute materials cause part of the decrease, and increased imports of finished electronic gear mean fewer mica parts are fabricated in the United States. Since 1979, consumption block mica has decreased at an average annual rate of about 20%. This decline is expected to continue, and, by 1995, consumption will decrease to 2,500 kilograms. Consumption of mica splittings, the major type of sheet mica consumed in the United States, also decreased sharply through the 1960's and

1970's. During the 1980's, consumption leveled off to between 900 and 1,000 tons per year. Decreases were due to the development of substitute electrical insulating materials, miniaturization of electrical equipment, and increased imports of foreign-built products. Consumption of splittings is expected to decrease very slightly in the near future, remaining between 800 and 1,000 tons through 1995.

Scrap and flake mica enters markets as ground mica, and demand tends to follow construction activity levels. With construction activity depressed, ground mica consumption has decreased steadily from about 103,000 tons in 1987 to 75,000 tons in 1991. In the near future, modest increases are expected in construction activity, which will probably bring ground mica consumption to about 100,000 tons by 1995.

The major end use, as a filler in joint compounds, will continue to account for 55% to 60% of the market. Consumption for other uses—in paints, well-drilling muds, and plastics—is expected to increase slightly by 1995.

¹American Society for Testing and Materials. Standard Specification for Natural Muscovite Block Mica and Thins Based on Visual Quality. D351-77 in 1984 Annual Book of ASTM Standards: Volume 10.01, Electrical Insulation — Specifications: Solids, Liquids, and Gases; Test Methods: Liquids and Gases; Electrical Protective Equipment for Workers. Philadelphia, PA, 1984, pp. 136-143.

²Skow, M. L. Mica—A Materials Survey. BuMines IC 8125, 1962, 240 pp.

³Production of high-quality sericite is included in the totals; however, figures for low-quality sericite, used principally for brick manufacturing, are not included.

⁴Industrial Minerals. No. 292, Jan. 1992, p. 17.

OTHER SOURCES OF INFORMATION

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Other Sources

- Engineering and Mining Journal.
- Industrial Minerals (London).
- Industrial Minerals and Rocks, 5th ed., AIME, 1983.
- Mining Engineering.
- The Economics of Mica 1989, Roskill Information Services Ltd.
- The Mica Industry Association.

TABLE 1
SALIENT MICA STATISTICS

		1987	1988	1989	1990	1991
United States:						
Production (sold or used by producers):						
Scrap and flake mica						
	thousand metric tons	146	130	119	109	103
Value	thousands	\$8,201	\$6,793	\$6,273	\$5,841	\$5,542
Ground mica						
	thousand metric tons	113	109	101	97	75
Value	thousands	\$22,376	\$23,687	\$22,443	\$21,610	\$17,286
Consumption:						
Block, muscovite	metric tons	26	14	7	6	6
Value	thousands	\$982	\$628	\$599	\$554	\$502
Splittings	metric tons	960	1,104	1,108	842	854
Value	thousands	\$1,417	\$1,544	\$1,703	\$1,414	\$1,427
Exports	metric tons	5,828	7,168	5,327	5,659	4,910
Imports	do.	11,450	14,478	15,834	15,876	15,695
World: Production	do.	*277,665	*251,229	*229,459	*210,786	*198,347

*Estimated. †Revised.

TABLE 2
STOCKPILE GOALS AND GOVERNMENT INVENTORIES FOR MICA,
DECEMBER 31, 1991

(Metric tons)

Material	Inventory				
	Goal	Stockpile grade	Non-stockpile grade	Available for disposal	1991 sales
Block:					
Muscovite, stained and better	1,134	2,266	94	153	2
Phlogopite	95	8	52	—	—
Film: Muscovite, 1st and 2d qualities	41	533	(¹)	468	—
Splittings:					
Muscovite	5,728	6,501	—	315	—
Phlogopite	422	674	—	253	—

¹ Less than 1/2 unit.

TABLE 3
SCRAP AND FLAKE MICA¹ SOLD
OR USED BY PRODUCERS IN
THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	Quantity	Value
1987	146	8,201
1988	130	6,793
1989	11	6,273
1990	109	5,841
1991:		
North Carolina	64	3,747
Other States ²	39	1,795
Total	103	5,542

¹Includes finely divided mica recovered from mica schist and high-quality sericite schist, and mica that is a byproduct of feldspar, kaolin, and lithium beneficiation.

²Includes California, Connecticut, Georgia, New Mexico, Pennsylvania, South Carolina, and South Dakota.

TABLE 5
FABRICATION OF MUSCOVITE
BLOCK MICA IN THE UNITED
STATES IN 1991, BY QUALITY

(Kilograms)

Quality	1990	1991
Good stained or better	817	835
Stained or lower ¹	5,193	5,088
Total	6,010	² 5,922

¹Includes punch mica.

²Data do not add to total shown because of independent rounding.

TABLE 4
GROUND MICA SOLD OR USED BY PRODUCERS IN
THE UNITED STATES, BY METHOD OF GRINDING

(Thousand metric tons and thousand dollars)

Year	Dry-ground		Wet-ground		Total	
	Quantity	Value	Quantity	Value	Quantity	Value
1987	101	15,140	12	7,237	113	² 22,376
1988	95	14,570	14	9,117	109	23,687
1989	88	13,409	13	9,034	101	22,443
1990	W	W	W	W	97	21,610
1991	W	W	W	W	75	17,286

W Withheld to avoid disclosing company proprietary data.

¹Domestic and some imported scrap. Low-quality sericite is not included.

²Data do not add to total shown because of independent rounding.

**TABLE 6
CONSUMPTION AND STOCKS OF MICA SPLITTINGS IN THE
UNITED STATES, BY SOURCE**

	India		Madagascar		Total ¹	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Consumption:						
1987	930	\$1,231	30	\$185	960	\$1,417
1988	1,069	1,338	30	206	1,104	1,544
1989	1,062	1,448	46	255	1,108	1,703
1990	W	W	W	W	842	1,414
1991	W	W	W	W	854	1,427
Stocks on Dec. 31:						
1987	408	NA	4	NA	412	NA
1988	439	NA	5	NA	444	NA
1989	496	NA	9	NA	505	NA
1990	W	NA	W	NA	632	NA
1991	W	NA	W	NA	612	NA

NA Not available. W Withheld to avoid disclosing company proprietary data.
¹Data may not add to totals shown because of independent rounding.

**TABLE 7
BUILT-UP MICA¹ SOLD OR USED IN THE
UNITED STATES, BY PRODUCT**

Product	1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Flexible (cold)	96	\$588	105	\$685
Heater plate	W	W	W	W
Molding plate	291	1,623	305	1,708
Segment plate	284	1,777	281	1,893
Tape	W	W	W	W
Other	190	2,223	148	1,415
Total	861	6,211	839	26,022

W Withheld to avoid disclosing company proprietary data. Included in "Other."
¹Consists of alternating layers of binder and irregularly arranged and partly overlapped splittings.
²Data do not add to total shown because of independent rounding.

**TABLE 8
GROUND MICA SOLD OR USED BY PRODUCERS IN THE
UNITED STATES, BY END USE**

(Thousand metric tons and thousand dollars)

End use	1990		1991	
	Quantity	Value	Quantity	Value
Joint cement	53	8,984	39	6,173
Paint	14	2,894	15	4,428
Plastics	2	675	1	560
Well-drilling mud	7	1,114	4	484
Other ¹	21	7,944	15	5,642
Total²	97	21,610	75	17,286

¹Includes mica used for molded electrical insulation, rubber, textile and decorative coatings, welding rods, and miscellaneous.
²Data may not add to totals shown because of independent rounding.

**TABLE 9
AVERAGE REPORTED PRICE
FOR DRY- AND WET-GROUND
MICA SOLD OR USED BY U.S.
PRODUCERS IN 1991**

(Dollars per metric ton)

Kind	Price
Wet-ground	640
Dry-ground	150
End uses:	
Joint cement	157
Paint	294
Plastics	423
Well-drilling mud	123
Other ¹	371

¹Includes mica used for molded electrical insulation, roofing, rubber, textile and decorative coating, welding rods, and miscellaneous.

TABLE 10
U.S. EXPORTS OF CRUDE AND RIFTED MICA, MICA POWDER, AND MICA WASTE IN 1991, BY COUNTRY

Country	Crude and rifted				Powder		Waste	
	Less than \$0.55 per kilogram		More than \$0.55 per kilogram		Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)				
Barbados	—	—	—	—	14	\$32	—	—
Belgium	—	—	—	—	160	73	—	—
Brazil	—	—	—	—	47	29	—	—
Canada	59	\$25	—	—	1,007	384	106	\$21
Chile	—	—	—	—	15	8	—	—
Colombia	—	—	—	—	126	46	—	—
Ecuador	—	—	—	—	5	3	—	—
France	34	12	11	\$7	112	43	—	—
Germany	69	24	—	—	233	67	—	—
Greece	—	—	—	—	16	11	—	—
Honduras	—	—	—	—	5	3	—	—
Hong Kong	—	—	—	—	5	13	11	3
India	—	—	18	80	—	—	—	—
Indonesia	—	—	—	—	32	14	—	—
Ireland	—	—	—	—	20	8	—	—
Italy	—	—	—	—	81	15	—	—
Japan	124	43	63	59	376	228	—	—
Korea, Republic of	—	—	5	3	256	178	—	—
Malaysia	—	—	8	7	10	8	—	—
Mexico	312	130	(¹)	3	374	236	21	39
Netherlands	—	—	—	—	235	130	—	—
New Zealand	16	5	95	140	—	—	—	—
Pakistan	—	—	—	—	5	4	—	—
Philippines	—	—	—	—	42	28	—	—
Saudi Arabia	—	—	—	—	49	12	—	—
Singapore	—	—	2	3	—	—	—	—
South Africa, Republic of	—	—	2	7	—	—	—	—
Spain	—	—	—	—	2	3	—	—
Sweden	—	—	—	—	9	11	—	—
Taiwan	12	4	—	—	120	89	—	—
Trinidad and Tobago	—	—	—	—	—	—	20	4
U.S.S.R.	—	—	—	—	4	3	—	—
United Arab Emirates	—	—	—	—	—	—	54	11
Uruguay	—	—	—	—	4	3	—	—
Venezuela	15	5	—	—	56	34	20	4
Total²	641	249	205	309	3,420	1,717	233	82

¹Less than 1/2 unit.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 11
U.S. EXPORTS OF WORKED MICA IN 1991, BY COUNTRY

Country	Plates, sheets		Other	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Antigua and Barbuda	1	\$5	(¹)	\$6
Australia	8	123	12	32
Austria	10	199	—	—
Bahamas, The	1	5	7	26
Barbados	(¹)	4	—	—
Belgium	1	19	—	—
Brazil	32	397	(¹)	5
Canada	93	2,099	42	1,056
Chile	1	4	—	—
Colombia	—	—	6	157
Costa Rica	1	3	—	—
Ecuador	1	7	—	—
France	—	—	2	67
Germany	5	413	19	67
Guatemala	1	3	—	—
Hong Kong	1	34	—	—
Ireland	—	—	(¹)	17
Israel	—	—	9	46
Italy	19	452	—	—
Japan	4	87	—	—
Korea, Republic of	—	—	4	97
Malaysia	(¹)	4	—	—
Mexico	45	886	16	440
Netherlands Antilles	2	9	—	—
New Zealand	34	176	—	—
Pakistan	—	—	(¹)	5
Panama	1	5	—	—
Peru	—	—	(¹)	5
Philippines	14	58	—	—
Saudi Arabia	(¹)	4	—	—
Singapore	—	—	(¹)	3
Spain	2	20	—	—
Suriname	(¹)	3	—	—
Sweden	1	50	—	—
Switzerland	2	40	—	—
Taiwan	3	128	6	136
Turks and Caicos Islands	—	—	(¹)	5
United Kingdom	(¹)	12	(¹)	7
Venezuela	2	7	2	23
Total²	286	5,255	125	2,199

¹Less than 1/2 unit.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 12
U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND RIFTED MICA IN 1991, BY COUNTRY

Country	Split block		Splittings		Other			
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Less than \$0.55 per kilogram		More than \$0.55 per kilogram	
					Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Brazil	—	—	—	—	300	\$103	—	—
China	—	—	8	\$23	—	—	37	\$95
France	(¹)	\$11	(¹)	19	—	—	—	—
India	126	142	1,203	1,079	2,434	505	5	51
Japan	(¹)	2	—	—	—	—	9	58
Madagascar	—	—	32	128	—	—	—	—
Total²	127	155	1,244	1,249	2,734	608	51	204

¹Less than 1/2 unit.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 13
U.S. IMPORTS FOR CONSUMPTION OF MICA POWDER AND WASTE IN 1991, BY COUNTRY

Country	Powder		Waste	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Belgium	7	\$5	—	—
Brazil	—	—	116	\$34
Canada	9,501	3,915	18	9
France	11	16	—	—
Germany	14	35	—	—
India	—	—	744	333
Japan	108	1,137	—	—
Madagascar	—	—	18	12
Norway	66	49	—	—
Switzerland	18	62	—	—
United Kingdom	(¹)	2	—	—
Total²	9,725	5,219	896	389

¹Less than 1/2 unit.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 14
U.S. IMPORTS FOR CONSUMPTION OF WORKED MICA IN 1991,
BY COUNTRY

Country	Plates, sheets		Other	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Argentina	—	—	77	\$208
Austria	(¹)	\$1	1	28
Belgium	380	3,112	—	—
Brazil	2	11	22	154
Canada	1	27	—	—
China	35	90	—	—
France	9	67	—	—
Germany	—	—	12	94
Hong Kong	—	—	11	25
India	45	397	157	736
Italy	—	—	2	18
Japan	29	220	34	297
Korea, Republic of	14	215	32	58
Norway	—	—	(¹)	5
Peru	(¹)	5	—	—
Switzerland	52	1,050	—	—
Taiwan	—	—	(¹)	11
United Kingdom	(¹)	1	(¹)	3
Total²	567	5,196	351	1,639

¹Less than 1/2 unit.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 15
SUMMATION OF U.S. MICA TRADE DATA

	Scrap and flake mica				Sheet mica			
	Powder		Waste		Unworked		Worked	
	Quantity (metric tons)	Value (thousands)						
Exports:								
1987	4,235	\$1,275	824	\$259	77	\$145	NA	\$4,748
1988	5,202	1,623	1,088	367	63	228	NA	6,148
1989	3,628	1,634	1,224	555	60	156	415	7,227
1990	4,319	2,050	580	646	148	272	612	7,568
1991	3,420	1,717	874	331	205	309	411	7,454
Imports for consumption:								
1987	5,672	2,685	3,916	1,243	1,116	1,230	746	5,125
1988	7,778	4,222	4,345	1,339	1,603	2,083	751	5,679
1989	8,902	4,971	4,185	1,256	1,616	2,054	1,129	6,711
1990	9,142	5,133	4,034	987	1,615	2,051	1,085	7,431
1991	9,725	5,219	3,630	996	1,422	1,608	918	6,835

NA Not available.

Source: Bureau of the Census.

TABLE 16
MICA: WORLD PRODUCTION, BY COUNTRY¹
(Metric tons)

Country ²	1987	1988	1989	1990	1991 ³
Argentina:					
Sheet	340	330	327	400	350
Waste, scrap, etc.	451	630	500	500	500
Brazil	2,415	2,520	3,700	4,990	5,000
Canada⁴	13,500	12,000	12,000	12,000	10,000
France⁴	9,300	9,000	8,000	7,000	6,000
India:					
Crude	4,240	3,839	4,186	3,860	3,662
Scrap and waste	6,307	3,694	3,121	2,822	3,000
Total	10,547	7,533	7,307	6,682	6,662
Iran⁴	2,450	1,127	2,294	1,352	1,000
Korea, Republic of (all grades)	31,938	18,848	7,888	4,765	5,000
Madagascar (phlogopite)	402	618	1,068	721	700
Mexico (all grades)	3,419	6,228	4,510	5,863	7,222
Morocco⁴	1,500	1,500	1,500	1,500	1,500
Mozambique⁴	(°)	(°)	—	—	—
Peru⁴	550	393	100	100	100
South Africa, Republic of (scrap)	970	1,669	1,708	1,765	1,883
Spain⁴	370	300	350	300	300
Sri Lanka	1,228	1,981	2,510	2,400	2,400
Sudan	5	—	—	—	—
Taiwan	787	4,387	4,290	4,000	4,300
Tanzania (sheet)	(°)	(°)	(°)	(°)	(°)
U.S.S.R. (all grades)⁴	50,000	50,000	50,000	45,000	40,000
United States (scrap and flake)⁵	145,650	129,900	119,142	108,845	102,830
Yugoslavia	1,043	768	794	802	800
Zimbabwe	800	1,797	1,471	1,801	1,800
Total	277,665	251,229	229,459	210,786	198,347

¹Estimated. ²Revised.

³Table includes data available through June 8, 1992.

⁴In addition to the countries listed, China, Norway, Pakistan, Romania, and Sweden are known to produce mica, but available information is inadequate to make reliable estimates of output levels.

⁵Reported figure.

⁶Data are for year beginning Mar. 21 of that stated.

⁷Less than 1/2 unit.

⁸Excludes U.S. production of low-quality sericite and sheet mica, if any.

MOLYBDENUM

By John W. Blossom

Mr. Blossom, a physical scientist/engineer with 44 years' industry and Government experience, has been the commodity specialist for molybdenum since 1982. Survey and trade data were prepared by Sherwood C. Jordan, mineral data assistant; and the world production tables were prepared by Harold D. Willis, international data coordinator.

Molybdenum is a refractory metallic element used principally as an alloying agent in steels, cast irons, and superalloys to enhance hardenability, strength, toughness, and wear and corrosion resistance. Primarily added in the form of molybdic oxide or ferromolybdenum, it is frequently used in combination with chromium, columbium, manganese, nickel, tungsten, or other alloy metals to achieve desired metallurgical properties. The versatility of molybdenum has ensured it a significant role in contemporary technology and industry, which increasingly require materials that are serviceable under higher stresses, greater temperature ranges, and more corrosive environments. Moreover, molybdenum finds significant usage as a refractory metal in numerous chemical applications, including catalysts, lubricants, and pigments. The variety of uses for molybdenum materials, few of which afford acceptable substitutions, has resulted in a demand that is expected to grow at a greater rate than most other ferrous metals.

Distribution of molybdenum reserves and productive capacity is concentrated in a few countries of the world. World mine output was an estimated 112 thousand metric tons (molybdenum contained in concentrate) in 1991, of which Canada, Chile, China, and the United States provided 85%. An estimated 19% of world output came from the U.S.S.R. These five countries, led by the United States, are expected to continue as the principal mine producers for the rest of this century. These countries also possess about 90% of the

estimated 11 million tons of molybdenum in world reserve base.

The metric system is the official system of measurement of most countries. The U.S. Bureau of Mines, in an effort to provide statistical data on molybdenum that are consistent with international usage, will henceforth report data in kilograms and metric tons.

DOMESTIC DATA COVERAGE

Domestic production data for molybdenum are developed by the U.S. Bureau of Mines by means of three separate, voluntary surveys. These surveys are Molybdenum Ore and Concentrate, Molybdenum Concentrate and Molybdenum Products, and Molybdenum Concentrates. Surveys are sent to all operations that produce molybdenum ore and products. Out of 14 operations to which surveys were sent, all responded, representing 100% of the total U.S. production shown in table 1.

BACKGROUND

From the period of the Greek and Roman civilizations to the late 18th century, terms such as "molybdous" or "molybdaena" were applied to minerals that were soft and "leadlike" in character, probably including minerals now known as galena, graphite, and molybdenite. This confusion was resolved in 1778 when the Swedish chemist, Karl Scheele, demonstrated that molybdenite, the principal molybdenum mineral, was a discrete mineral sulfide. Four years later, P. J. Hjelm of Sweden reduced the

acid-forming oxide of the element by heating with charcoal, thereby producing an impure powder of the metal, which he named "molybdenum." Various properties of the element and its compounds were determined during the 19th century, and in 1893, German chemists produced a 96%-pure metal by reducing calcium molybdate. The impure metal was reported to have been used experimentally as a substitute for tungsten in tool steels.

Molybdenum-bearing armorplate was produced in France in 1894; this was the first recorded use of the metal as an alloying element in steel. Soon thereafter, Henri Moissiam, a French chemist, succeeded in producing a 99.98%-pure metal by reduction of molybdenum in an electric furnace. Moissiam then conducted studies to establish the element's atomic weight and to determine its physical and chemical properties. These studies stimulated interest in the metal and its compounds and investigations of commercial applications. By the late 1890's, molybdenum was used in certain chemicals and dyes, and in 1898, a self-hardening molybdenum tool steel was marketed.

The first mine production of molybdenite was probably from the Knaben Mine in southern Norway in the late 18th or early 19th century. Because essentially no commercial use for the metal existed, output from the mine remained insignificant until about 1880. By the end of the century, molybdenum ore was also mined intermittently in Australia and the United States.

Molybdenite and wulfenite concentrates were produced from ores in Arizona and New Mexico, but U.S. output was small and ceased entirely in 1906 owing to lack of demand.

World War I generated the first appreciable utilizations of molybdenum, when it was substituted for tungsten in high-speed steels and used as an alloying element in certain steels for military armament. From 1912 to 1920, small output was recorded from several additional countries, and U.S. production was resumed. The flotation process for separating molybdenite from its ores was developed during these years. The Climax deposit in Colorado and the Questa deposit in New Mexico were initially exploited from 1917 to 1919. Development of the Climax deposit, the world's largest, later proved the viability of high-tonnage extraction of relatively low-grade ore and established the United States as the leading producer of molybdenum.

Output terminated in 1920 in the United States and most other countries because nonmilitary consumption of molybdenum was insufficient to support continued production. However, industrial efforts to develop peacetime applications, primarily as an alloy in steels and cast irons, were successful, and by the mid-1920's, demand exceeded that of the war years. Operations resumed at the Climax deposit in 1924. By 1930, world output of molybdenum totaled 4.2 million pounds, of which the United States and the Climax Mine accounted for about 89% and 73%, respectively.

In 1933, the Greene Cananea Copper Co., a Mexican subsidiary of the Anaconda Co., initiated the recovery of molybdenite as a byproduct of copper mining operations. Three years later, Kennecott Corp. began byproduct recovery at its Bingham open pit in Utah. Since that time, molybdenite recovery circuits have been installed at numerous copper concentrating plants, notably in Canada, Chile, and the United States. These sources have supplied 40% to 50% of the world molybdenum output in recent years.

Since the early 1930's, industrial research and marketing programs have considerably expanded the range of metallurgical materials in which molybdenum is a preferred or essential alloy ingredient. The use of molybdenum as a refractory metal and in a variety of chemical applications has also experienced significant growth.

Definitions, Grades, and Specifications

Molybdenum is a silver-white metallic element with an atomic number of 42, atomic weight of 95.95, and a density of 10.2 grams per cubic centimeter. The chemistry of molybdenum is complex; molybdenum exhibits oxidation states from -2 to 6, coordination numbers from 4 to 8, and forms compounds with most inorganic and organic liquids. Molybdenum is a strong carbide-forming element, and much of its alloying effect in steel is imparted through the formation of carbides. It has a melting point of about 2,610° C; among the metallic elements, only osmium, rhenium, tantalum, and tungsten have higher melting points. Other significant physical properties of molybdenum metal are good thermal conductivity (about one-half that of copper), the lowest coefficient of thermal expansion of the pure metals, high strength at elevated temperatures, and resistance to corrosion in a wide variety of mediums. Molybdenum metal is stable in air or water at moderate temperatures, but above 500° C, it oxidizes readily.

Molybdenite is the principal mineral from which molybdenum is obtained. Crude ore containing molybdenite is beneficiated to produce molybdenite concentrate. The concentrate generally contains about 90% molybdenite; the grade may be somewhat lower, particularly if produced at copper byproduct concentrating plants. Technical-grade molybdic oxide is produced by the roasting of molybdenite concentrate. Typically, the oxide has a content of 85% to 90%, or a minimum of 57% contained molybdenum. Other raw materials, including ferromolybdenum, purified molybdic oxide, ammonium, and

sodium molybdate, and molybdenum metal powder are produced from technical-grade oxide. The production of these materials is described in the section entitled "Products for Trade and Industry."

The American Society for Testing and Materials (ASTM) has developed standards for the chemical composition of molybdenum oxide products (Specification A 146-64, reapproved 1979) and ferromolybdenum (Specification A 132-74, reapproved 1979). These standards specify minimums for molybdenum content and maximums for impurity content as an aid to producers and purchasers. Material marketed by the major domestic producers generally meet or exceed ASTM standards.

Products for Trade and Industry

Some commercial-grade molybdenite concentrate is treated in additional grinding and flotation steps to produce lubricant-grade molybdenum disulfide. Oil and water are volatilized by passing an upgraded concentrate through an inert-gas-swept kiln. The oil-free product is about 99% molybdenum disulfide and suitable for use in lubricant applications.

Molybdenite concentrate is converted to technical-grade molybdic oxide, the major form of molybdenum used by industry and the base material for production of ferromolybdenum, chemicals, and molybdenum metal powder. The technical-grade oxide is produced by roasting molybdenite concentrate in the multiple-hearth furnace at temperatures of up to 650° C. Typically, the roasted product contains 90% molybdic oxide and a maximum of 0.1% sulfur. Technical-grade oxide is used to add molybdenum to steels, cast irons, and other alloys.

Ferromolybdenum is typically produced by reduction of technical-grade oxide and iron oxide with a conventional metallothermic process, using silicon and/or aluminum as the reductant. The molybdenum content ranges from 58% to 64%. Ferromolybdenum is used as a

alternative additive in producing alloy steels, cast irons, and nonferrous alloys.

Ammonium molybdate is produced by reacting pure molybdic oxide with ammonium hydroxide and crystallizing out the pure molybdate. Sodium and calcium molybdate are made in a similar manner using sodium hydroxide and calcium chloride.

Molybdenum metal powder is manufactured by reducing pure molybdic oxide or ammonium molybdate with hydrogen. The purest metal powder (99.95% molybdenum minimum) is produced from ammonium molybdate. Metal powder is pressed and sintered into small metal ingots, which are converted into rod, wire, or sheet by hot rolling, swaging, or forging. Large ingots are produced by arc-casting powder under a vacuum or inert gas atmosphere.

Industry Structure

Five countries, Canada, Chile, China, the U.S.S.R., and the United States, mine 90% of world output of molybdenum ore. Plants to convert ore concentrates to technical-grade oxide and other molybdenum products are in Chile, China, the U.S.S.R., the United States, and Western Europe.

Geology-Resources

Almost all molybdenum is recovered from low-grade deposits of the mineral molybdenite. Deposits mined primarily for molybdenum provide 45% of U.S. output and about 21% of world output. The remainder is obtained mainly as a byproduct from mining of large, low-grade copper porphyry deposits. Primary molybdenum deposits generally grade 0.2% to 0.5% molybdenite; copper ores from which byproduct molybdenum is recovered contain 0.02% to 0.08% molybdenite.

The average crustal abundance of molybdenum is 1 to 2 parts per million (ppm). The molybdenum content of igneous rocks tends to increase with increasing silica content. Molybdenum does not occur in nature in its free or native state, but is found only chemically

combined with other elements. Small deposits of molybdenum-bearing minerals occur throughout the world, but the only molybdenum mineral of commercial importance is molybdenite. Wulfenite, powellite, and ferrimolybdite are common but have supplied very little molybdenum.

Molybdenite (MoS_2) is a lead-gray metallic mineral that characteristically occurs in thin, tabular, commonly hexagonal plates and also disseminated as fine specks. It has a specific gravity of 4.6 to 4.7, a hardness of 1 to 1.5, a greasy feel, and it soils the fingers. Superficially, it resembles graphite, for which it commonly has been mistaken.

Molybdenum deposits are of five geological types: (1) porphyry or disseminated deposits, including stockworks and breccia pipes in which metallic sulfides are dispersed through relatively large volumes of altered and fractured rock, (2) contact-metamorphic zones and tactite bodies of silicated limestone adjacent to intrusive granitic rocks, (3) quartz veins, (4) pegmatites and aplite dikes, and (5) bedded deposits in sedimentary rocks.

The first three genetic-type deposits are hydrothermal in origin and as such represent nearly all the known molybdenum resources currently mined in the world. The remaining types do not represent a great volume of molybdenum but are of certain economic importance only when molybdenum is associated with other minerals.

In the hydrothermal deposits, metallic minerals are precipitated from high-temperature aqueous solutions either by changes in temperature and pressure or by evaporation of the liquid. Minerals are deposited in the cavities, cracks, or interstices of the matrix rock.

Most of the porphyry coppers contain small quantities of molybdenite disseminated with the copper minerals through large bodies of granitic rock. The chief minerals are chalcopyrite and chalcocite, with pyrite and small amounts of other sulfides, including molybdenite.

Available information on world reserves and reserve base of molybdenum varies widely in reliability. For certain countries such as Canada, Chile, and the

United States, company annual reports or other published materials enable inventorying minable ore reserves. For most other countries, reserves must be estimated from fragmentary or preliminary data on ore tonnage and grade of known or anticipated sources. In particular, the reserve figures for China and the U.S.S.R. should be considered order-of-magnitude estimates.

It should be noted that the reserve data refer to molybdenum contained in ore. The recovery of molybdenum after milling approximates 75% to 90% of the in-place ore content at primary molybdenum sources. Recoveries achieved at byproduct sources vary markedly from mine to mine, but average an estimated 55% of the molybdenum in ore processed. Overall, an estimated 65% of the total world molybdenum reserves can be considered as recoverable.

Most of the world reserves of molybdenum occur in the western mountain regions of North and South America, extending from Alaska and British Columbia through the United States and Central America to the Andes Mountains of Chile. These regions, roughly bordering the eastern margin of the Pacific Basin, are also regarded as most promising for future discoveries and additions to reserves.

Technology

Exploration.—Prospecting and exploration for molybdenum is basically the same as that for deposits of other metals. Areas generally considered favorable for molybdenite mineralization are those metallogenic provinces that encompass known occurrences of molybdenum stockworked deposits and copper-molybdenum porphyry deposits. An understanding of regional geology, mineral associations, and known patterns of molybdenite mineralization is essential to identify potential sites for field investigation. Sites for detailed study may be selected on the basis of geologic mapping of rock units and structures, geochemical analyses of sediments and soils, and ground geophysical surveys.

An intensive drilling and sampling program is then required to estimate the size, grade, and continuity of the discovery. Exploration drifts may be driven into the ore body to provide more specific geologic information and bulk samples for metallurgical testing.

The evaluation of a deposit may require 2 to 5 years from the time of discovery. During this time, the technical, economic, and environmental aspects of mine development must be evaluated. An additional 3 to 8 years may be required to prepare the deposit for production. Long development times are indicative of the complex planning and considerable capital needed to develop the large, low-grade stockwork and porphyry deposits that are expected to remain the significant sources of molybdenum. As a general rule, development of underground molybdenum deposits would require more time and capital than that of surface deposits.

Mining.—Molybdenum ore is mined by underground and open pit methods, the choice of method determined by the size, configuration, grade, and depth of the ore body. Underground and surface operations accounted for about 40% and 60%, respectively, of the domestic molybdenum output.

Underground deposits of molybdenum ore are mined by block or panel caving methods modified to suit the characteristics of the particular ore body being worked. In these methods, large masses of ore are undercut and blasted at the base to induce the collapse and fragmentation of the ore under its own weight. The broken ore may be drawn off from the caved mass by gravity through finger raises into slusher drifts. The ore is then scraped to draw holes where it falls into ore cars on a haulage level beneath the slusher drifts. Alternatively, the broken ore may be funneled by gravity to crosscut drifts at intervals between production drifts. Ore is moved from the ends of the crosscuts along the production drifts to ore passes where it is dumped and collected in loading pockets on a deeper main haulage level. Ore is then transported from the

main haulage level to the site of the initial milling operations. Caving methods are used to mine underground deposits of molybdenum because the low grade of the ore necessitates extraction of large tonnages of rock at a minimum of cost. However, caving of the ore must be carefully controlled to avoid ore dilution and excessive ground stresses to mine openings.

In open pit mining operations, the ore is exposed by removal of waste rock. The cut in the ore takes the form of benches, which vary in height and width from mine to mine. The cycle of open pit extraction consists of drilling, blasting, loading, and haulage. Primary drilling consists of driving a vertical blasting hole into the ore. Secondary drilling and blasting may be required to break large boulders. Ore is loaded by mechanical shovels into rail cars or trucks and hauled by large trucks for short distances or by train for long distances. Skipways and belt conveyors are used at some mines for transporting ore to the mill site.

Beneficiation.—Because of their low molybdenum content, all molybdenum-bearing ores require beneficiation. After crushing and grinding to a suitable size, both primary molybdenite and copper sulfide ore containing molybdenite are beneficiated by flotation. With primary ores, a final concentrate of 90% to 95% molybdenite is produced by subjecting the ore to several stages of grinding and reflation. Copper, iron, and lead minerals are generally the critical impurities that must be minimized in the final concentrate product. Overall recovery of molybdenite at primary-ore concentrating plants ranges from 75% to 90% of the in-place ore content.

Production of molybdenite concentrate from copper ores is more difficult, however, because molybdenite constitutes less than 0.1% of the ore. As a byproduct value, molybdenite recovery is generally given less priority than recovery of copper values. In some cases, improved molybdenite recovery may be attained only at the expense of reduced

copper recovery or lower grade of copper concentrate produced.

Recovery from copper ores begins with the bulk flotation of copper minerals and molybdenite as the first separation from gangue materials. Molybdenite in the bulk flotation product is then separated from the copper minerals in a selective flotation process, which usually involves the flotation of molybdenite and depression of copper minerals. The separatory flotation requires close control of pH, reagent mix, and several flotation steps. Processing of copper-molybdenum ore varies from plant to plant depending on the grade of mineralization and impurities in the ore. Concentrate produced as a byproduct contains 70% to 90% molybdenite, although most approaches the higher end of the range in content.

Recycling.—Some secondary molybdenum is recovered in the production of alloy steels, superalloys, and the metal, but data on quantities are incomplete and inconclusive. Most of this recycled material is generated and reused directly at metal-forming or fabricating plants (runaround scrap) or shipped to plants that reclaim it (prompt industrial scrap). Very little molybdenum-containing obsolete scrap is processed for its molybdenum content. Although some molybdenum is recycled as a minor constituent of scrap alloy steels, the use of such scrap does not generally depend on its molybdenum content. An increasing quantity of molybdenum is being reclaimed from spent catalysts and chemical residues.

Byproducts and Coproducts

Tin, tungsten, and a very minor quantity of pyrite are recovered as byproducts from molybdenum ore at the Climax deposit in Colorado. Rhenium is extracted from flue gases and dust produced during the roasting of molybdenite concentrate that has been produced as a byproduct of copper mining.

Molybdenum is recovered as a byproduct primarily from copper ores. A

very small amount is also obtained from tungsten and uranium ores. At the Sierrita Mine in Arizona, copper and molybdenum are considered coproduct values.

Substitutes

Historically, molybdenum has been a relatively inexpensive alloying agent used primarily in specialty steels and alloys, and in the United States, it has been readily available. As a result, metallurgical applications for molybdenum were broadened, and its utility as an alloy ingredient became well recognized. The substitution for molybdenum by other alloy metals has had little impetus.

Several factors mitigate the possible replacement of molybdenum to the degree that its overall demand would be significantly affected. First, there is no acceptable substitute in numerous metallurgical and chemical uses. Second, it is commonly added to steels and alloys to enhance several desired properties (such as hardenability, strength, corrosion resistance, etc.), often in synergistic effect with other alloy metals. In such cases, molybdenum could be replaced for particular effects, but at a sacrifice in overall performance. Moreover, the molybdenum content of alloy and specialty steels ranges from less than 1 to a few percent. Therefore, costs of molybdenum raw materials have to increase substantially to appreciably affect the cost of the finished product, thereby stimulating substitution. Finally, the United States is self-sufficient in molybdenum, a situation unlike that of many other ferrous metals. Significant replacement would entail increases in the imports of substituted metals.

Nevertheless, possible alternatives exist in most applications of molybdenum. Steels and alloys containing less or no molybdenum might be used in place of those with higher molybdenum content. In most cases, such substitution would result in lowered or unacceptable performance. Boron, chromium, and manganese can replace molybdenum in steels where hardenability is the only

desired effect. In certain low-alloy steels, columbium, manganese, and vanadium act in similar fashion to molybdenum. Chromium, nickel, and tungsten are possible substitutes in steels and other alloys. Molybdenum has substantially replaced tungsten in high-speed tool steels; a return to tungsten grades is possible, but with a reduction in economy and performance. Nonmetallurgical materials, such as plastics and ceramics, can replace steels and alloys containing molybdenum in certain applications.

Tungsten and tantalum can be substituted for molybdenum in certain refractory metal uses, but as a cost disadvantage. Molybdenum can be replaced by graphite for refractory elements in electric furnaces in the range of 1,000° to 1,600° C, but at the expense of slightly greater difficulty in operation and control. Chrome orange, cadmium red, and organic orange pigments are possible substitutes for molybdenum orange. Acceptable substitutes for molybdenum are not found in most of its major catalytic applications. Graphite and other solid lubricants generally do not perform as well as molybdenum disulfide, especially under high-pressure and high-temperature conditions.

Economic Factors

The prices of molybdenum products are quoted on a contained-molybdenum basis and reflect, at least partially, the cost of conversion. Technical-grade oxide, the major form of molybdenum sold commercially, varies slightly in price depending on purity, type of packaging, and whether it is briquetted.

Price quotations generally fall under two groups, the producer-marketer and the merchant. The producer-marketer mines and concentrates the ore, converts the concentrates into consumer products, and markets these products, while a merchant buys and sells concentrates and may convert concentrates into products that are marketed. The source for the merchant to buy concentrates is the byproduct producer. The byproduct producer prices his byproduct as one that

provides extra credit. Therefore, this type of a producer is not likely to hold back concentrates from sale. The producer-marketer tries to keep the market balanced by setting a price-based cost plus profit and varying the output to maintain a balance.

Operating Factors

Environmental Requirements.—The mining of molybdenum ore and disposal of ore tailings disturb land areas. Land reclamation is part of the ongoing mining operation. Development of new mining and milling complexes present local socioeconomic and land-use problems. Because new potentially economic sources are likely to be found in relatively unpopulated regions with little other industry, development of a major mine can have significant impact on established occupational patterns. Interaction between mining firms and local, State, and Federal agencies are required to ensure that mine development proceeds in as orderly and environmentally sound manner as is possible. The conversion of molybdenite concentrate to technical-grade molybdic oxide involves roasting. Roasting facilities have been modified with sulfuric acid recovery equipment to reduce emissions and thereby comply with stringent environmental restrictions.

Toxicity.—Compared to other industrial metals, molybdenum exhibits very low, negligible toxicity. No significant toxic effects in human beings have been identified in mining or processing of molybdenum materials. As an environmental trace element, molybdenum is an essential micronutrient. Deficiencies of molybdenum can affect the normal growth and development of plant and animal species.

Employment.—Employment in the past decade has reduced by a factor of five with about the same tonnage of production. This improvement in productivity was due to changes in mining and milling equipment and methodologies.

ANNUAL REVIEW

Domestic and foreign molybdenum markets for concentrates diminished in 1991. Domestic stock levels increased 7%. U.S. mine output of molybdenum was about 47% of world production. Reported end-use consumption of molybdenum in raw materials decreased by 6% from that of the previous year. Exports of all forms of molybdenum from the United States decreased, while imports of molybdenum also decreased. Domestic producer stocks of molybdenum products increased about 63% from that of the previous year. Domestic mine production of molybdenum concentrate decreased to a total of 53,000 tons of contained molybdenum compared with 62,000 tons in 1990. World mine production of molybdenum concentrate also decreased from a total of 122,000 tons in 1990 to 112,000 tons in 1991. Canada, Chile, China, the U.S.S.R., and the United States accounted for more than 90% of the molybdenum produced worldwide. (See tables 1, 2, and 3.)

Consumption and Uses

Consumption of molybdenum concentrate decreased 2,500 tons in 1991. Domestic mine production of molybdenum concentrate was either roasted, exported for conversion, or purified to lubrication-grade molybdenum disulfide. The consumption in 1991 of technical-grade molybdc oxide decreased from that of the previous year. Oxide is the chief form of molybdenum utilized by industry, particularly in steel, cast iron, and superalloys. However, some of the material is also converted to other molybdenum products, such as ferromolybdenum, high-purity oxide, ammonium and sodium molybdate, and metal powder. Apparent U.S. consumption (defined as U.S. primary plus secondary production plus imports minus exports plus adjustments for Government and industry stock changes) was about 19,000 tons of molybdenum. (See table 4.)

Stocks

Total industry stocks, which include those of producers and consumers, increased about 1,000 tons of contained molybdenum. Inventories of molybdenum in concentrate at producer locations decreased about 2,400 tons. Producer stocks of molybdenum in consumer products, such as oxide, ferromolybdenum, molybdate, metal powders, and other types, decreased about 3,500 tons. Compared with apparent consumption, yearend producer stocks of these materials represented about a 10-month supply. Domestic consumer inventories of about 2,600 tons, the same amount as at yearend 1990, represented approximately a 2-month supply as measured by average monthly reported consumption. (See table 5.)

Prices

The "Metals Week Dealer" (MWD) price of molybdc oxide (per kilogram of contained molybdenum) decreased from \$5.99 in January to \$4.95 at the end of December 1991. The average MWD price of oxide was \$5.27 or \$0.35 less than the average MWD price in 1990.

The posted producer price (AMAX Inc. and Cyprus Minerals Co.) for molybdc oxide was \$7.39 during 1991. (See table 6.)

Foreign Trade

Exports of molybdenum in concentrate and of oxide decreased compared with those of 1990. Molybdenum concentrate exports were about 63% of domestic mine production. Approximately 95% of reported shipments of concentrate and oxides were made to Belgium, Chile, France, Germany, Japan, the Netherlands, and the United Kingdom. The calculated molybdenum content of all exports was about 37,000 tons in 1991. Total value of exports decreased from \$209 million in 1990 to \$154 million in 1991.

Approximately 2,600 tons of molybdenum in various forms was imported into the United States, about the

same as that in 1990. Total value of all forms of molybdenum imported decreased from \$28 million in 1990 to \$26 million in 1991. In terms of both value and quantity, the major form imported was ferromolybdenum, principally from Chile and China. (See tables 7, 8, 9, and 10.)

World Review

Capacity.—The data in table 11 are rated capacity for mines and mills as of December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. Mine capacity for molybdenum is based on published reports, production statistics, and estimates. (See table 11.)

Reserves.—The definitions of reserves and reserve base are published in U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification For Minerals," which is reprinted in the U.S. Bureau of Mines "Mineral Commodity Summaries, 1991."

Estimated world reserves and reserve base of molybdenum appear in table 12. The United States, with a reserve base of molybdenum estimated at 11.8 million tons, has 45% of the world molybdenum reserve base. About 90% of U.S. reserves occur in large porphyry or disseminated deposits mined, or anticipated to be mined, primarily for molybdenum. These deposits are in Alaska, Colorado, Idaho, Nevada, New Mexico, and Utah. Other molybdenum sources contribute insignificantly to U.S. reserves.

Canadian reserves of primary molybdenum are in British Columbia, including 30% of the total in the Endako

primary deposit. Other Canadian reserves are associated with molybdenum and copper-molybdenum porphyry deposits in British Columbia and in relatively minor sources in Quebec and New Brunswick.

Molybdenum reserves in Central and South America are mainly in large copper porphyry deposits. Of several such deposits in Chile, the Chuquicamata and El Teniente deposits are among the world's largest and account for 85% of total molybdenum reserves in Chile. Mexico and Peru have substantial reserves. The La Caridad deposit in Mexico is a large producer. Numerous other copper porphyries that may contain recoverable quantities of molybdenum have been identified in Central and South America. Many of these deposits are actively being explored and evaluated and could add substantially to reserves in the future.

Reserves of molybdenum in China and the U.S.S.R. are estimated to be substantial, but definitive information about the current sources of supply or prospects for future development in the two countries is lacking. Copper ores are being investigated on the islands of New Guinea and Bougainville in the southwest Pacific, but it is not known whether these contain economically recoverable molybdenum. (See table 12.)

OUTLOOK

Capital expenditures are expected to decrease from that of the previous year to a more normal level over the next few years. Alloy and stainless steel demand is forecast to decline in 1992. Short-term molybdenum demand is expected to remain a little below that of 1991. Molybdenum production must be adjusted to reduce inventories that have been built up during 1991. The long-term demand depends on world events and the ability to meet the needs of capital expenditures for environmental controls and to expand the manufacturing capacity.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

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Canadian Mining Journal (Canada). Annual reports of various companies.
Engineering and Mining Journal.
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TABLE 1
SALIENT MOLYBDENUM STATISTICS

(Metric tons of contained molybdenum unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Concentrate:					
Production	34,073	43,051	63,105	61,611	53,364
Shipments	31,692	45,240	61,733	61,580	53,607
Value	thousands				
	\$179,286	\$266,899	\$421,427	\$346,262	\$249,909
Reported consumption	16,983	35,690	41,877	35,455	32,998
Imports for consumption	'2,954	'514	'238	'478	161
Stocks, Dec. 31: Mine and plant	6,841	4,732	6,969	7,672	5,267
Primary products:					
Production	15,721	25,646	27,985	28,764	33,714
Shipments	18,447	20,535	18,277	17,983	19,105
Stocks, Dec. 31	10,055	7,116	6,675	5,918	9,387
Reported consumption, by end use	14,800	17,422	17,204	'18,060	16,931
World: Mine production	'99,471	'107,360	'130,299	'122,232	'112,224

*Estimated. †Revised.

TABLE 2
PRODUCTION, SHIPMENTS, AND STOCKS OF MOLYBDENUM
PRODUCTS IN THE UNITED STATES

(Metric tons of contained molybdenum)

	1990		1991		1990		1991	
	Metal powder		Other ¹		Total			
Received from other producers	W	W	3,339	3,724	3,339	3,724		
Gross production during year	2,122	2,305	26,642	31,409	28,764	33,714		
Used to make other products listed here	W	W	13,038	12,923	13,038	12,923		
Net production	W	W	15,727	20,791	15,727	20,791		
Shipments	875	493	17,108	18,612	17,983	19,105		
Producer stocks, Dec. 31	254	142	5,664	9,246	5,918	9,387		

W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Includes ferromolybdenum, molybdic oxides, phosphomolybdic acid, molybdenum disulfide, molybdic acid, ammonium molybdate, calcium molybdate, sodium molybdate, molybdenum metal, pellets, molybdenum pentachloride, molybdenum hexacarbonyl, and data indicated by symbol W.

TABLE 3
MOLYBDENUM: WORLD MINE PRODUCTION, BY COUNTRY¹

(Metric tons of contained molybdenum)

Country ²	1987	1988	1989	1990	1991 ³
Bulgaria [*]	200	200	190	180	160
Canada (shipments)	14,771	13,535	13,543	¹ 12,188	11,000
Chile	16,941	¹ 15,515	16,550	13,830	³ 14,540
China [*]	¹ 12,000	¹ 14,400	¹ 15,700	¹ 15,700	16,000
Iran [*]	¹ 500	¹ 700	¹ 750	¹ 500	500
Korea, Republic of	325	144	132	¹ 103	100
Mexico	4,400	4,456	4,189	¹ 3,200	2,550
Mongolia [*]	¹ 1,400	¹ 1,400	¹ 1,450	¹ 1,500	1,000
Niger [*]	8	15	13	10	10
Peru	3,353	2,444	3,177	¹ 2,410	3,000
U.S.S.R. [*]	11,500	11,500	11,500	11,000	10,000
United States	34,073	43,051	63,105	61,611	³ 53,364
Total	¹ 99,471	¹ 107,360	¹ 130,299	¹ 122,232	112,224

^{*}Estimated. ¹Revised.

²Table includes data available through June 5, 1992.

³In addition to the countries listed, North Korea, Romania, Turkey, and Yugoslavia are believed to produce molybdenum, but output is not reported quantitatively, and available general information is inadequate to make reliable estimates of output levels.

⁴Reported figure.

TABLE 4
U.S. REPORTED CONSUMPTION OF MOLYBDENUM, BY END USE

(Hundred kilograms contained molybdenum)

End use	Molybdic oxides	Ferro molyb- denum ¹	Ammonium and sodium molybdate	Other ²	Total ³
1990					
Steel:					
Carbon	4,614	1,082	—	218	5,913
Stainless and heat resisting	32,492	1,996	—	736	35,224
Full alloy	29,845	11,831	—	315	41,991
High-strength low-alloy	4,989	3,622	—	—	8,611
Tool	5,567	2,263	—	32	7,863
Cast irons	1,355	7,402	—	124	8,880
Superalloys	7,612	559	—	11,294	19,464
Alloys:					
Welding materials (structural and hard-facing)	—	861	—	43	904
Other alloys ⁴	W	W	—	833	833
Mill products made from metal powder	—	—	—	20,702	20,702
Chemical and ceramic uses:					
Pigments	W	—	W	—	W
Catalysts	9,076	—	W	1,793	10,870
Other	36	W	W	4,473	4,509
Miscellaneous and unspecified	2,331	724	11,481	298	14,834
Total³	97,918	30,339	11,481	40,861	180,599
1991					
Steel:					
Carbon	5,098	1,208	—	344	6,649
Stainless and heat resisting	30,746	2,230	—	657	33,632
Full alloy	28,664	9,458	—	198	38,321
High-strength low-alloy	3,877	3,371	—	—	7,248
Tool	3,402	1,681	—	179	5,262
Cast irons	726	5,434	—	132	6,292
Superalloys	8,126	474	—	9,825	18,425
Alloys:					
Welding materials (structural and hard-facing)	—	805	—	44	849
Other alloys ⁴	W	W	—	639	639
Mill products made from metal powder	—	—	—	24,338	24,338
Chemical and ceramic uses:					
Pigments	14	—	W	—	14
Catalysts	8,650	—	9,024	1,793	19,468
Other	W	W	W	3,802	3,802
Miscellaneous and unspecified	1,965	601	1,552	248	4,366
Total³	91,268	25,263	10,576	42,199	169,306

¹Revised. W Withheld to avoid disclosing company proprietary data; included in "miscellaneous and unspecified."

²Includes calcium molybdate.

³Includes purified molybdenum disulfide, molybdenite concentrate added directly to steel, molybdenum metal powder, molybdenum metal, pellets, and other molybdenum materials.

⁴Data may not add to totals shown because of independent rounding.

⁵Includes magnetic and nonferrous alloys.

TABLE 5
INDUSTRY STOCKS OF MOLYBDENUM MATERIALS, DECEMBER 31

(Metric tons of contained molybdenum)

	1987	1988	1989	1990	1991
Concentrate: Mine and plant	6,841	4,732	6,969	7,672	5,267
Producers:					
Molybdc oxides ¹	W	4,816	W	W	W
Metal powder	207	136	124	254	142
Other ²	9,848	2,164	6,551	5,664	9,246
Total ³	10,055	7,116	6,675	5,918	9,387
Consumers:					
Molybdc oxides ¹	1,657	1,581	1,627	¹ 1,558	1,579
Ferromolybdenum ⁴	251	260	235	² 219	218
Ammonium and sodium molybdate	34	25	19	² 24	28
Other ⁵	745	752	703	⁷ 786	771
Total ³	2,688	2,618	2,584	² 2,587	2,596
Grand total ³	19,584	14,466	16,229	¹ 16,177	17,250

⁰Revised. W Withheld to avoid disclosing company proprietary data; included with "Producers: Other."

¹Includes technical and purified molybdc oxide and briquets.

²Includes ferromolybdenum, phosphomolybdc acid, molybdenum disulfide, molybdc acid, ammonium molybdate, sodium molybdate, calcium molybdate, molybdenum metal, pellets, molybdenum pentachloride, and molybdenum hexacarbonyl.

³Data may not add to totals shown because of independent rounding.

⁴Includes calcium molybdate.

⁵Includes purified molybdenum disulfide, molybdenite concentrate added directly to steel, molybdenum metal powder, molybdenum metal, pellets, and other molybdenum materials.

TABLE 6
DOMESTIC PRICE LISTINGS FOR
MOLYBDENUM

(Per kilogram of contained metal)

	1990	1991
Merchant quotes: ¹		
Concentrate (byproducts)	\$5.623	\$4.692
Ferromolybdenum-export	8.502	7.570
Oxide	5.859	5.270
Producer quotes: Oxides	7.380	7.387

¹Average.

Source: Metals Week.

TABLE 7
U.S. EXPORTS OF MOLYBDENUM ORE AND CONCENTRATES
(INCLUDING ROASTED AND OTHER CONCENTRATES), BY COUNTRY

(Metric tons)

Country	1990		1991	
	Quantity (contained molybdenum)	Value (thou- sands)	Quantity (contained molybdenum)	Value (thou- sands)
Australia	141	\$618	206	\$893
Belgium	9,107	39,092	6,467	23,513
Brazil	37	159	255	713
Canada	259	1,562	210	1,385
Chile	1,298	4,250	1,235	2,774
China	—	—	323	1,010
France	899	2,747	1,757	5,346
Germany, Federal Republic of	2,858	10,410	2,372	8,014
India	196	816	80	298
Japan	4,844	22,383	5,479	21,349
Korea, Republic of	—	—	256	749
Mexico	2,272	14,806	37	203
Netherlands	7,941	36,935	7,694	31,497
Sweden	372	1,431	202	876
United Kingdom	10,957	32,956	6,734	13,707
Other	200	1,723	117	1,382
Total¹	41,380	169,888	33,424	113,709

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 8
U.S. EXPORTS OF MOLYBDENUM PRODUCTS, BY PRODUCT AND COUNTRY

(Metric tons)

Product and country	HTS No.	1990		1991	
		Quantity	Value (thousands)	Quantity	Value (thousands)
Oxides and hydroxides, gross weight:	2825.70.0000				
Argentina		(¹)	\$3	—	—
Australia		7	45	9	\$55
Belgium		120	530	83	334
Canada		176	1,188	212	1,286
Japan		364	2,576	358	2,181
Korea, Republic of		43	221	23	127
Mexico		51	354	1	35
Netherlands		14	84	171	1,138
Taiwan		8	54	—	—
Other		4	40	713	4,521
Total ²		787	5,095	1,571	9,678
Molybdates—all, contained weight:	2841.70.0000				
Canada		335	2,102	342	1,901
China		8	49	—	—
Japan		220	1,155	273	1,446
Korea, Republic of		55	322	18	105
Mexico		12	95	28	85
Singapore		2	13	—	—
Taiwan		15	91	35	175
Other		35	136	40	252
Total ²		680	3,963	740	3,965
Ferromolybdenum, contained weight: ³	7202.70.0000				
Canada		82	610	82	579
Japan		144	1,265	238	2,095
Malaysia		(²)	4	11	96
Mexico		11	93	8	50
Singapore		—	—	5	30
Venezuela		25	168	20	116
Other		38	232	10	92
Total ²		300	2,372	375	3,058
Powder, gross weight:	8102.10.0000				
Belgium		—	—	1	69
Brazil		20	516	4	107
Canada		6	195	5	147
China		4	74	—	—
France		98	661	13	359
Germany, Federal Republic of		25	256	3	142
India		14	215	10	158
Italy		3	66	2	65
Japan		26	961	54	1,687
Mexico		4	60	7	160
Netherlands		2	45	12	161

See footnotes at end of table.

TABLE 8—Continued
U.S. EXPORTS OF MOLYBDENUM PRODUCTS, BY PRODUCT AND COUNTRY

(Metric tons)

Product and country	HTS No.	1990		1991	
		Quantity	Value (thousands)	Quantity	Value (thousands)
Powder, gross weight—Continued:	8102.10.0000				
Sweden		21	\$309	32	\$374
Taiwan		48	888	49	947
United Kingdom		5	\$132	14	\$364
Other		18	186	24	167
Total ²		292	4,565	230	4,907
Molybdenum unwrought, gross weight:	8102.91.0000				
Canada		33	852	30	495
France		(¹)	11	(¹)	9
India		—	—	1	4
Japan		71	824	31	356
Mexico		5	19	1	26
Netherlands		66	644	18	259
United Kingdom		1	20	—	—
Other		4	82	5	52
Total ²		180	2,453	88	1,204
Molybdenum wrought, gross weight:	8102.92.0000				
Australia		(¹)	5	4	22
Austria		6	122	—	—
Brazil		(¹)	18	1	52
Canada		7	295	4	209
France		9	688	11	587
Germany, Federal Republic of		39	1,804	20	1,079
Japan		25	1,487	31	1,827
Korea, Republic of		36	194	1	69
Mexico		2	99	2	78
Netherlands		6	462	5	453
Singapore		(¹)	11	(¹)	36
South Africa, Republic of		1	80	(¹)	9
Sweden		1	22	1	60
United Kingdom		52	2,044	18	762
Other		6	264	12	324
Total ²		190	7,595	110	5,570
Wire, gross weight:	8102.93.0000				
Argentina		2	75	3	67
Belgium		8	604	47	1,637
Brazil		23	902	19	759
Canada		10	385	6	258
France		42	1,365	21	748
Germany, Federal Republic of		166	3,865	91	2,270
India		6	261	14	593
Italy		31	1,145	19	693
Japan		34	1,597	48	1,798

See footnotes at end of table.

TABLE 8—Continued
U.S. EXPORTS OF MOLYBDENUM PRODUCTS, BY PRODUCT AND COUNTRY

(Metric tons)

Product and country	HTS No.	1990		1991	
		Quantity	Value (thousands)	Quantity	Value (thousands)
Wire, gross weight—Continued:	8102.93.0000				
Korea, Republic of		12	\$632	17	\$850
Mexico		8	341	11	472
Netherlands		(¹)	26	—	—
Singapore		—	—	1	79
Taiwan		3	\$120	8	\$392
United Kingdom		11	520	4	240
Other		2	110	16	314
Total ²		388	12,863	360	12,053

¹Less than 1/2 unit.

²Data may not add to totals shown because of independent rounding.

³Ferromolybdenum contains about 60% to 65% molybdenum.

Source: Bureau of the Census.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF MOLYBDENUM

Item	HTS No.	1990			1991		
		Gross weight (metric tons)	Contained molybdenum	Value (thousand dollars)	Gross weight (metric tons)	Contained molybdenum	Value (thousand dollars)
Molybdenum ore and concentrates, roasted	2613.10.0000	913	433	2,874	167	100	554
Molybdenum ore and concentrates, other	2613.90.0000	142	45	310	106	61	328
Molybdenum oxides and hydroxides	2825.70.0000	643	NA	3,569	948	NA	5,013
Molybdates of ammonium	2841.70.0000	109	61	614	139	77	772
Molybdates—all others	2841.70.5000	4	2	13	(¹)	(¹)	(¹)
Molybdenum orange	3206.20.0000	916	NA	2,579	812	NA	2,399
Mixtures of inorganic compounds	3823.90.3400	1	(²)	103	1	(²)	105
Ferromolybdenum	7202.70.0000	1,401	871	6,990	1,521	953	7,304
Molybdenum powders	8102.10.0000	79	71	1,771	32	28	821
Molybdenum unwrought	8102.91.1000	58	39	2,147	64	45	1,596
Molybdenum waste and scrap	8102.91.5000	214	202	1,866	371	363	3,238
Molybdenum wrought (includes bars, rods, profiles, plate, sheets, strips, foil)	8102.92.0000	61	NA	4,217	53	NA	3,275
Molybdenum wire	8102.93.0000	3	NA	249	2	NA	211
Molybdenum, other	8102.99.0000	2	NA	720	2	NA	495
Total ³		4,545	XX	28,022	4,217	XX	26,111

NA Not available. XX Not applicable.

¹No data recorded.

²Less than 1/2 unit.

³Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 10
HARMONIZED TARIFF SYSTEM ON MOLYBDENUM IN THE UNITED STATES

Type trade	HTS No.	Commodity description	Quantity (kilograms)	Rates of duty		
				General Most favored nation	Special ¹	Non-most favored nation
Molybdenum ore and concentrates:						
Import	2613.10.0000	Molybdenum ore and concentrates, roasted	Contained	13.2 cents/kg on molybdenum content + 1.9% ad valorem	Free (E,IL) 9.2 cents/kg on molybdenum content + 1.3% ad valorem (CA)	\$1.10/kg on molybdenum content + 15% ad valorem.
Export	2613.10.0000	do.	do.	—	—	—
Import	2613.90.0000	Molybdenum ore and concentrates, other	do.	19.9 cents/kg on molybdenum content + 1.9% ad valorem	Free (E,IL) 7.9 cents/kg on molybdenum content + 1.3% ad valorem (CA)	77.2 cents/kg on molybdenum content + 15% ad valorem.
Export	2613.90.0000	do.	do.	—	—	—
Molybdenum chemicals:						
Import	2825.70.0000	Molybdenum oxides and hydroxides	Gross	3.2% ad valorem	Free (A, E, IL) 1.2% ad valorem (CA)	20.5% ad valorem.
Export	2825.70.0000	do.	do.	—	—	—
Do.	2841.70.0000	Molybdates—all	Contained	—	—	—
Import	2841.70.1000	Molybdates of ammonium	do.	4.3% ad valorem	Free (A, E, IL) 1.7% ad valorem (CA)	29% ad valorem.
Do.	2841.70.5000	Molybdates—all others	do.	3.7% ad valorem	Free (A, E, IL) 1.4% ad valorem (CA)	25% ad valorem.
Export	3206.20.0000	Pigments based on chromium (molybdenum orange, etc.)	Gross	—	—	—
Import	3206.20.0020	Molybdenum orange	do.	3.7% ad valorem	Free (A, E, IL)	25% ad valorem. 1.4% ad valorem (CA).
Export	3823.30.0000	Nonagglomerated metal binders, molybdenum, etc.	do.	—	—	—
Import	3823.90.3400	Mix of two or more inorganic compounds of molybdenum	Contained	2.8% ad valorem	Free (A, E, IL)	18% ad valorem.
Ferroalloys:						
Export	7202.70.0000	Ferromolybdenum	do.	—	—	—
Import	7202.70.0000	do.	do.	4.5% ad valorem	Free (E, IL) 1.8% ad valorem (CA)	31.5% ad valorem.
Do.	8102.10.0000	Powders	do.	13.9 cents/kg on molybdenum content + 1.9% ad valorem	Free (E, IL) 5.5 cents/kg on molybdenum content + 0.7% ad valorem (CA)	\$1.10/kg on molybdenum content + 15% ad valorem.

See footnotes at end of table.

TABLE 10—Continued
HARMONIZED TARIFF SYSTEM ON MOLYBDENUM IN THE UNITED STATES

Type trade	HTS No.	Commodity description	Quantity (kilograms)	Rates of duty		
				General Most favored nation	Special ¹	Non-most favored nation
Ferroalloys—Continued:						
Export	8102.10.0000	Powders	Gross	—	—	—
Do.	8102.91.0000	Unwrought, waste and scrap	do.	—	—	—
Import	8102.91.1000	Unwrought	Contained	13.9 cents/kg on molybdenum content + 1.9% ad valorem	Free (E, IL) 5.5 cents/kg on molybdenum content + 0.7% ad valorem (CA)	\$1.10/kg on molybdenum content + 15% ad valorem.
Do.	8102.91.5000	Waste and scrap	do.	Free	—	Free.
Do.	8102.92.0000	Wrought	Gross	6.6% ad valorem	Free (A, E, IL) 2.6% ad valorem (CA)	60% ad valorem.
Export	8102.92.0000	do.	do.	—	—	—
Import	8102.93.0000	Wire	do.	6.6% ad valorem	Free (A, E, IL) 2.6% ad valorem (CA)	60% ad valorem.
Export	8102.93.0000	do.	do.	—	—	—
Import	8102.99.0000	Other	do.	5.5% ad valorem	Free (A, E, IL) 2.2% ad valorem (CA)	45% ad valorem.
Export	8102.99.0000	do.	do.	—	—	—

¹Symbols for programs are as follows: A Generalized System of Preferences; CA United States-Canada Free-Trade Agreement; E Caribbean Basin Economic Recovery Act; IL United States-Israel Free Trade Area.

TABLE 11
WORLD MOLYBDENUM ANNUAL
PRODUCTION CAPACITY,
DECEMBER 31, 1991

(Hundred metric tons of contained molybdenum)

Country	Rated capacity ¹
Bulgaria	9
Canada	159
Chile	204
China	45
Iran	18
Korea, Republic of	9
Mexico	68
Mongolia	23
Niger	(²)
Peru	45
U.S.S.R.	159
United States	748
Total	1,487

¹Includes capacity at operating plants as well as at plants on standby basis.

²Less than 1/2 unit.

TABLE 12
MOLYBDENUM RESERVES AND
RESERVE BASE

(Thousand metric tons of contained molybdenum)

	Reserves	Reserve base
North America:		
Canada	450	910
Mexico	90	230
United States	2,720	5,350
Other	—	90
South America:		
Chile	1,130	2,450
Peru	140	230
Other	—	90
Europe:		
Bulgaria	(¹)	10
U.S.S.R.	450	680
Other	—	270
Asia:		
China	500	1,220
Iran	50	140
Other	—	140
Total	5,530	11,810

¹Less than 1/2 unit.

NICKEL

By Peter H. Kuck

Dr. Kuck has been a physical scientist with the U.S. Bureau of Mines since 1979 and was previously responsible for iron ore, silicon, and vanadium. Domestic survey data were prepared by Barbara J. McNair, Ferrous Data Section. International data tables were prepared by William L. Zajac, Chief, and Audrey D. Wilkes, Section of International Data.

Nickel is vital to the stainless steel industry and has played a key role since the beginning of the 20th century in the development of the chemical and aerospace industries. The element (symbolized by Ni) is critical in a highly industrialized and technological society because of its myriad of applications. Nickel's greatest value is as an alloying agent with other metallic elements, adding strength and corrosion resistance over a wide range of temperatures.

Domestic and Western World nickel demand dropped slightly in 1991, following 6 years of continuous growth. Demand for nickel in the Western World was about 670,000 metric tons (mt), 3,000 mt less than the record high of 1990.¹ Prices remained at relatively high levels throughout the year in spite of the general economic downturn. In 1990, the United States signed an agreement with the U.S.S.R. that allowed the Soviets to resume exports of nickel and nickel-containing products, such as stainless steel, to the United States. With the dissolution of the U.S.S.R. and the creation of a market economy in the Republic of Russia, large tonnages of primary nickel were shifted from the Soviet military-industrial complex to markets in Western Europe, Japan, and the United States. This influx of Russian material accelerated in early 1992, exerting a downward pressure on nickel prices in the second half of 1992.

The United States produced 1.21 million metric tons (Mmt) of nickel-bearing stainless steel in 1991, a drop of 8% from that of the previous year.² In Japan, however, production of nickel-

bearing stainless steel was up almost 3%.³ Japan has been the largest stainless steel producer in the Western World for more than a decade and made 2.01 Mmt of hot-rolled, nickel-bearing stainless in 1991.

DOMESTIC DATA COVERAGE

The U.S. Bureau of Mines canvassed all known nickel consumers whose annual consumption was greater than 2 mt. Of the 272 annual forms sent, 184 responses were received, representing 68% of the total canvassed. Estimates for nonrespondents were made by comparing data reported in prior years with current consumption trends. Reported primary consumption, based on data from monthly and annual canvass forms and estimates, was 79% of apparent primary consumption. Apparent consumption is defined as primary nickel produced from domestic ores plus scrap recovery plus imports minus exports plus adjustments for Government and industry stock changes. (See table 1.)

BACKGROUND⁴

Definitions, Grades, and Specifications

Primary nickel is normally marketed as either nickel metal, nickel oxide sinter, or ferronickel. Commercial nickel metal is more than 99.5% pure and may be in the form of square plates, powder, briquets, pellets, ingots, disks, or shot. The square plates are referred to as "cathode" because they are cut from an electrolytic cathode sheet at the end of the refining process. The ferronickel produced in the

United States contains 48% to 52% Ni and is sold in 28-pound ingots; that produced in other countries may contain anywhere from 20% to 50% Ni. In 1992, Glenbrook Nickel Co., the sole U.S. producer, began marketing ferronickel shot for the first time—again with a 48% to 52% Ni content. Nickel oxide sinter contains either 77% or 90%+ Ni. Almost all of the 90%+ grade imported into the United States comes from the Yabulu refinery of the Queensland Nickel Joint Venture (QNJV) in Australia.

Most nickel compounds are divalent, although the oxidation state can vary from -1 to +4. The chloride, the sulfate hexahydrate, and the nitrate hexahydrate are used in electroplating. The sulfate is also used as a colorant and as a starting material for some catalysts. The oxide, hydroxide, and peroxide are preferred for fuel cell and battery manufacturing.

Industry Structure

At least 23 countries mined some type of nickel ore in 1991. In almost every case, the nickel came from either a laterite deposit or a sulfide deposit. Four other countries had active smelters and/or refineries. Most producing companies tend to favor one of the two deposit types at the expense of the other because of significant differences in how the ores are processed. Inco Ltd. is an exception owing to the global nature of its operations. Because laterites are formed by surface water percolating downward through ultramafic rock, most laterite deposits are either in the tropics or in

subtropical to temperate coastal regions that have a long geologic history of heavy rainfall. Sulfide deposits, on the other hand, can occur almost anywhere, ranging from central Africa to the high Arctic.

The nickel in laterite ores is usually processed into ferronickel because (1) the ores have a high iron content and (2) the ores are more easily smelted than concentrated. Sulfide ores are more amenable to concentration and hydrometallurgical refining. Over the 5-year period from 1987 through 1991, laterite operations accounted for about 33% of world mine production, with the balance coming from sulfide operations. The Norilsk Nickel Combine of Russia is currently the largest producing company in the world, followed by Inco Ltd. of Canada. For 1987 through 1991, the six largest producing countries and their share of world mine production were as follows: the Commonwealth of Independent States (C.I.S.) (29%), Canada (21%), New Caledonia (9%), Australia (7%), Indonesia (7%), and Cuba (4%).

The Sudbury district of Ontario continues to be one of the principal sources of nickel for the world. Falconbridge Ltd. and Inco operate most of the mines in the Sudbury Basin. Other important nickel mining regions are the Noril'sk district of central Siberia, the western half of the Kola Peninsula, and the Kambalda district of Western Australia. The only U.S. producer is Glenbrook Nickel, which operates a ferronickel smelter at Riddle, OR. Some nickel is also produced in the United States as a byproduct of copper refining and recycling.

Geology-Resources

Nickel is the Earth's fifth most abundant element, but occurs in the Earth's crust only in the range of 0.008% to 0.02% by weight. The bulk of the nickel is believed to be concentrated in the Earth's core. Geologic studies indicate that most nickel deposits have been derived from ultramafic rocks, such as peridotite or serpentinite. These are

igneous rocks that are low in quartz and feldspar, but high in ferromagnesian silicates. The nickel content of ultramafic rocks, although relatively high compared with that of other rocks, seldom exceeds 0.3% by weight. These values are too low to make them economically minable as nickel ore. Because nickel tends to follow iron and can be readily incorporated into either silicates or sulfides, the element is less likely to be concentrated in an economically viable deposit than some less abundant elements, such as copper and lead. To be rich enough to mine, some natural process must have concentrated the nickel. These processes result in the two very different types of nickel deposits mentioned earlier.

Nickel laterites are formed by the weathering of ultramafic rocks. As the rocks weather, nickel, iron, and sometimes cobalt are taken into solution by descending meteoric water and redeposited at greater depth, producing a zone of enrichment. The water is initially acidic because of the presence of organic acids and dissolved carbon dioxide. As the metal-bearing water descends, it reacts with the bed rock and becomes more basic. The cobalt and iron tend to precipitate out first, forming a limonite zone that averages 0.8% to 1.5% Ni and is rich in nickeliferous goethite $[(Fe,Ni)OOH]$. Further down, a point is reached where the bulk of the nickel precipitates out, together with the accompanying magnesium and silica. This second zone of enrichment typically contains 1.8% to 3.5% Ni. Here, the principal ore mineral is garnierite, a hydrous nickel-magnesium silicate.

Nickel sulfide deposits, on the other hand, are formed by some type of igneous or metamorphic activity, such as the intrusion of molten ultramafic rock or the alteration of the host rock by hydrothermal solutions. The principal ore minerals are pentlandite $[(Fe,Ni)_9S_8]$ and nickeliferous pyrrhotite $(Fe_{1-x}S)$. Millerite (NiS) is regarded as a secondary, supergene mineral at Sudbury, but can also occur as a primary mineral in some lower temperature types of deposits. Heazlewoodite (Ni_3S_2) , niccolite/nickeline $(NiAs)$, and the

various linnaeite end members $[(Fe,Co,Ni)_3S_4]$ are normally present in only minor amounts. At Sudbury, pentlandite and pyrrhotite are frequently associated with chalcopyrite $(CuFeS_2)$ and, to a lesser degree, cubanite $(CuFe_2S_3)$. As a result, copper is an important byproduct for both Falconbridge and Inco. Cobalt and platinum-group metals are also being recovered from the sulfide concentrate.

Nickel sulfide deposits are found in both volcanic and plutonic settings. The sulfides can occur as massive ore, disseminated blebs, breccia fillings, or vein fillings. Economic geologists have developed a variety of depositional models to explain these different features. One of the more popular plutonic concepts involves magmatic segregation and crystal settling, in which a molten magma slowly intrudes upward through the country rock. As the magma cools, the nickel and other metals combine with sulfur to form dense immiscible droplets that settle to the bottom of the magma chamber. This model can be used to explain some of the geologic phenomena observed at Sudbury and at the Bushveld Igneous Complex in the Republic of South Africa. However, the segregation model exhibits several inconsistencies and is far from perfect. Sudbury's origin remains controversial, with one group of geologists postulating that ore genesis was initiated by the impact of an asteroid or large meteorite.

Substitutes

With few exceptions, substitutes for nickel would result in increased cost or some sacrifice in the performance of the product. Present and potential nickel substitutes include aluminum, coated steels, and plastics in the construction and transportation industries; nickel-free specialty steels in the power generating, petrochemical, and petroleum industries; titanium and plastics in severe corrosive applications; and cobalt, copper, and platinum in catalytic uses.

Economic Factors

Prices.—Nickel prices have traditionally been quite volatile. Table 2 shows the time-price relationship for the metal over a 50-year span. The upward price trend in the 1970's reflected generally strong demand. In the early 1980's, excess production capacity caused nickel prices to drop. In terms of constant dollars, nickel prices in the mid-1980's were at their lowest levels since the end of World War II. Between 1984 and 1986, producers were forced to close at least six production facilities; some others were on the verge of failure and lost large amounts of money. World consumption, driven by stainless steel demand, rebounded dramatically in late 1987, reaching record levels that year and in each of the next 3 years. Prices soared along with demand. In mid-1992, the cycle began to repeat itself when demand for stainless weakened in Japan and parts of Europe. Nickel prices turned downward after large amounts of Russian cathode appeared in Western warehouses. (See table 2.)

Costs.—There are several significant factors that determine the cost of producing nickel. They include the type and nickel content of the ore, the mining method, transportation, infrastructure, energy prices, labor and materials, regulatory compliance, and credits from recoverable byproducts.

Generally, nickel can be recovered from sulfide ores at a lower cost than from laterite ores because sulfides are more readily concentrated using established mineral dressing methods. On the other hand, virtually all of the laterite deposits are open pit operations and, therefore, less costly to mine. Most sulfide deposits occur at depth and have to be mined from underground. Shaft sinking, timbering, roof bolting, lighting, ventilation, and pumping all drive up costs. The absence of massive, primary sulfide deposits at the surface is understandable. Many sulfide minerals readily oxidize to sulfates when exposed to air for an extended period of time. Sulfuric acid forms when

copious amounts of water are present, accelerating the oxidation process.

Energy consumption is the most significant cost in recovering nickel from laterite ores. Estimates indicate that for every \$1 increase in the price of a barrel of crude oil, there is a corresponding increase of \$0.05 per pound (lb) of nickel produced at operations that are dependent on oil for both drying and smelting. It does not seem to matter much whether the laterite ore is converted to ferronickel or to matte. Sulfide ores, on the other hand, do not have to be dried, and, unlike laterite ores, are more amenable to concentration.

Byproduct revenues can significantly reduce net production costs. Smelters that convert laterite ores to ferronickel produce only slag, iron, and occasionally electrical power as byproducts. Smelters that process laterite ores using a chemical leaching method sometimes recover cobalt as a byproduct. In contrast, sulfide operations generate revenues from the recovery of byproduct copper, cobalt, and precious metals. The Sudbury nickel deposits are an important source of both platinum and palladium. The principal platinum mineral is sperrylite, PtAs₂, while much of the palladium is tied up in bismuthides and bismuth tellurides. Some sulfide facilities also profit from the sale of byproduct liquid sulfur dioxide and sulfuric acid.

The costs of complying with air pollution control regulations can be significant. Dust generated in the processing of laterite ores can be controlled using relatively inexpensive equipment. In contrast, a large capital investment is required to reduce sulfur dioxide emissions from a smelter processing nickel-copper sulfide concentrates. During the past 10 years, Inco has allocated 12% of its total capital expenditures to attain compliance with Canadian regulations limiting sulfur dioxide emissions.

In 1991, the U.S. Bureau of Mines published an information circular entitled "Availability of Primary Nickel in Market-Economy Countries."⁵ This report evaluated the availability of nickel from 36 deposits or districts in 16

market-economy countries, analyzing more than 95% of production capacity in those countries. The study determined the quantity of nickel available on the basis of net production costs and total costs with both a 0% and a 10% discounted cash-flow rate of return. Costs of production were expressed in dollars per pound of recovered nickel. The study also indicated sensitivities of the cost of production to energy, labor, and similar factors. The deposits and properties in the study contained approximately 33 Mmt of recoverable nickel. Sensitivity studies performed for both laterite and sulfide deposits indicated that the total cost of producing nickel from laterites was most sensitive to increases in energy costs and that the total cost of producing nickel from sulfide deposits was most sensitive to increases in labor costs; sulfides were also affected by changes in revenues from byproducts.

Operating Factors

Environmental Requirements.—The principal environmental problem associated with nickel production is the emission of sulfur dioxide (SO₂) from smelters that process sulfide ores. The SO₂ emitted from smelter smokestacks combines with water in the atmosphere to form droplets of sulfuric acid (H₂SO₄), a major component of acid rain. The Provincial government of Ontario has ordered Inco to reduce SO₂ emissions at its Sudbury complex by two-thirds and has imposed a ceiling of 260,000 metric tons per year (mt/yr), starting in 1994. The company is spending \$410 million on state-of-the-art pollution control equipment to meet the new limit. The only alternative would have been to reduce production by two-thirds from 1989 levels.

Nickel smelters have a much higher sulfur burden than their copper and zinc counterparts. As a rule of thumb, 1 mt of sulfur is generated for each mt of copper produced. In contrast, 8 mt of sulfur is generated for each mt of nickel.

Recent environmental legislation and other responses to environmental concerns are expected to significantly

affect future nickel consumption. In some cases, the effect will be positive; in others, negative.

In November 1990, the Congress amended the Clean Air Act (CAA), updating Federal air pollution standards for the first time since 1977 and completely overhauling the hazardous air pollutants program. The amendments (Public Law 101-549), among other things, put controls on airborne emissions of nickel metal, its compounds, and alloys. Nickel compounds were specifically included in the new list of 189 hazardous air pollutants to be regulated. The law also directed the U.S. Environmental Protection Agency (EPA) to develop, by November 15, 1991, a preliminary list of pollution source categories that warranted regulation. A number of nickel consumers appeared on the November list, including steel mills, iron and steel foundries, nonferrous foundries, and sintering operations.⁶ Primary nickel producers, producers of nickel sulfate, and nickel-cadmium (Ni-Cd) battery manufacturers were also listed, together with secondary copper smelters and secondary zinc smelters. At yearend, EPA was assigning priorities to the listed categories as part of a 10-year phase-in of the CAA regulations. Maximum Achievable Control Technology Standards were to have been established for the 40 most important source categories by November 15, 1992.

Because new pollution control equipment will probably be needed to comply with these standards, the enactment of the Clean Air Act Amendments was expected to increase demand for stainless steel and other alloys of nickel. Under the new law, 111 fossil fuel-fired powerplants must reduce their SO₂ emissions by 1995. This particular section of the law was enacted to help control acid rain. The 111 plants—a total of 251 generating units—were specifically targeted because each emits more than 2.5 lb of SO₂ per million British thermal units (mmBtu). Not all of the plants exceeding the 2.5-lb level, though, will necessarily have to reduce their emissions. It appears that the EPA will require compliance on a systemwide

basis. Some utilities may be able to meet the overall compliance requirements by drastically reducing emission levels at a few of their heavier polluting facilities. Some plants can reduce SO₂ emissions by simply switching to fuels that contain lower levels of sulfur; others will be forced to install scrubbers (flue gas desulfurization units).

In any event, electric utilities will need increasing amounts of stainless steel over the next 20 years. Because so few powerplants were built during the 1980's, construction programs may soon have to be accelerated if the projected demand for electricity is to be met. A significant amount of stainless will not only go into pollution control equipment, but also into turbines.

Under the CAA, few, if any, new plants will be permitted to emit more than 1.2 pounds per million British thermal units (lb/mmBtu). Because it is far cheaper and easier to include scrubbers in the design of a new plant than to retrofit an existing facility, many, if not most, of the new plants will be equipped with some type of scrubbing system. About 100 mt of metal will be required for each scrubber. Although it is not clear which alloys will be used, most will probably contain significant nickel because of the element's ability to improve the resistance of different metals to corrosion and heat.

The California Air Resources Board has voted to list all forms of nickel, including metallic nickel, as toxic air contaminants. The board took the action even though the nickel and metal plating industries had questioned the validity of the risk assessment information assembled by the board's staff. The next step was to have been the preparation of a needs assessment, identifying major nickel emitting sources in California. The assessment would involve estimating emission rates together with associated exposure levels and risks. Technically feasible controls and costs would also be identified. The board indicated that issues such as particle size would have to be closely examined as controls are developed.

In July 1990, the EPA published proposed drinking water standards for

nickel and other materials. The maximum contaminant level goal for nickel was set at 0.1 milligram per liter.

Toxicity.—Data compiled by the EPA indicate that, of the 17 substances covered by the Agency's Industrial Toxics Project, nickel and its compounds showed the highest increase of reported releases from 1988 to 1989. This increase has heightened concerns in several areas.

The American Conference of Governmental Industrial Hygienists (ACGIH) postponed action on a proposal to set more stringent recommended workplace limits for nickel and its compounds. The ACGIH had proposed reducing the workplace limits, or threshold limit values (TLV's), for nickel metal and all nickel compounds to 0.05 milligrams per cubic meter (mg/m³) and to designate nickel metal and all inorganic nickel compounds as confirmed human carcinogens. Action on the more stringent values was postponed until 1993 so that existing scientific evidence could be weighed more carefully and additional evidence, expected to become available in the interim, could be evaluated. ACGIH guidelines are important because the U.S. Occupational Safety and Health Administration (OSHA) and regulatory agencies in other countries weigh them carefully in determining mandatory permissible exposure limits for the workplace.

The Nickel Producers Environmental Research Association (NiPERA), among others, had urged the ACGIH not to reduce the current TLV's for nickel metal and all nickel compounds. The 8-hour TLV is currently set at 1.0 mg/m³ for insoluble forms of nickel (e.g., NiO) and 0.1 mg/m³ for soluble forms of nickel (e.g., NiSO₄). In comments to the ACGIH TLV committee, NiPERA argued that new epidemiological information suggests that there would not be a measurable increase in cancer incidence or mortality at the current threshold values. NiPERA felt that it was not necessary to reduce the current TLV to protect against adverse nonmalignant respiratory effects and recommended that

ACGIH wait until the results of ongoing studies being sponsored by the U.S. National Toxicology Program and by NiPERA were released.

In 1990, the International Committee on Nickel Carcinogenesis in Man published a study intended to clarify the nature and extent of the risks that nickel and its compounds pose to humans.⁷ Called the Doll Committee, after its chairman, Sir Richard Doll of Oxford University, the committee's conclusions were based on an analysis of various epidemiological studies of individuals exposed to nickel in the workplace. The main conclusion was that workers exposed to very high concentrations of oxidic and/or sulfidic nickel did indeed have an increased risk of getting lung or nasal sinus cancer. The threshold concentration in air seemed to be about 1 mg/m³ in the case of soluble nickel compounds and more than 10 mg/m³ for less soluble ones. Exposure levels of this magnitude are no longer tolerated at North American smelters and refineries. There was no evidence to suggest that occupational exposure to metallic nickel increased the risk for any type of cancer. However, the metal can cause an allergic reaction in some individuals. The risk to the general population from exposure to extremely small concentrations of airborne nickel compounds (less than 1 microgram Ni/m³) was minute and, possibly, nonexistent. The study was sponsored by, among others, the EPA, NiPERA, and Energy, Mines, and Resources—Canada.

ANNUAL REVIEW

Legislation and Government Programs

The U.S.S.R. resumed exporting nickel and nickel-containing products, such as stainless steel, to the United States under an agreement that took effect on June 28, 1990. In 1983, the U.S. Department of the Treasury banned the importation of these materials from the U.S.S.R. The action was taken to prevent nickel of Cuban origin from being marketed in the United States. At that time, almost one-half of the total nickel production of Cuba

was being exported to the U.S.S.R. Most of that material was concentrate for refining to electrolytic nickel.

As part of the 1990 agreement, Raznoimport, a Soviet trade organization, had to certify that exports of nickel and nickel-bearing products were exclusively of Soviet origin. Certificates of origin were required for products from both the Norilsk Mining and Metallurgical Plant at Norilsk in the Krasnoyarsk region and the Nickel Industrial Amalgamation Plant at Monchegorsk in the Murmansk region. According to the Bureau of the Census, the United States imported 1,429 mt of cathode and 79 mt of powder and/or flake from the former U.S.S.R. in 1991. Combined imports of cathode from Russia and Estonia in 1992 were expected to about triple the 1991 figure. All of the Estonian material was believed to be of Russian origin.

Strategic Considerations

Nickel is an essential ingredient in austenitic stainless steel and most superalloys. As such, its availability is important to the national security. Domestic mine capacity was less than 5% of primary apparent consumption in 1991. Canada, however, a close ally and a geographically secure source, is capable of supplying U.S. needs under normal circumstances.

Issues

The Defense Logistics Agency, of the U.S. Department of Defense, has submitted a plan to the Congress calling for large cuts in the National Defense Stockpile. Under the plan, the proposed goal for nickel would fall from the current 181,437 mt to zero, and at least 29,212 mt of the 33,760 mt of nickel in inventory would be sold or bartered over a 5-year period. Legislation supporting the disposal was passed by the Congress on October 5, 1992, and signed into law by the President on October 23. (Title XXXIII of Public Law 102-484: The Defense Authorization Act of 1992). Several nickel producers were concerned that the proposed long-term selloff would

unduly disrupt an already weakened North American market.

The new law established an advisory committee to oversee stockpile operations and a market impact committee to minimize market disruptions. The advisory committee was to be composed of officials from seven different Federal agencies as well as representatives from a mix of industries. The impact committee also was required to consult with industry on a regular basis.

The EPA was in the early stages of developing regulatory standards for shipping and processing recyclable materials that contain nickel and other transition elements. The Agency was still soliciting comments on the approach it will take to determine whether a solid waste is hazardous. The toxic constituents under review are listed in Appendix VIII of Subpart D of Title 40, Code of Federal Regulations, Part 261—Identification and Listing of Hazardous Waste. Nickel metal and its compounds both appear on the list, with nickel carbonyl and nickel cyanide being singled out for special scrutiny. EPA's approach is to classify appendix VIII constituent-bearing waste as hazardous only after analysis leads the Agency to conclude that the waste is capable of posing a substantial environmental or human health hazard when mismanaged. Some environmentalists disagree and have pressed EPA to presume that a waste containing a measurable amount of any appendix VIII constituent is hazardous, unless the Agency determines otherwise. This second approach could discourage recycling and elevate disposal costs for some relatively benign wastes that contain small quantities of nickel.

Production

Glenbrook Nickel Co., the only domestic nickel producer, continued to mine and smelt local laterite ore at its Riddle, OR, complex. The company is a joint venture of Cominco American Inc. and Cominco Resources International Ltd. The Riddle smelter was also using spent hydrogenation catalysts containing 5% to 10% Ni as supplemental feedstock. The

laterite deposit on Nickel Mountain has been mined intermittently since 1954, when Glenbrook's predecessor, the Hanna Nickel Smelting Co., first developed the property. In 1986, Hanna closed the smelter but left sizable stocks of low-grade coarse ore on hand. Glenbrook decided to acquire the Riddle operation after the 1988 surge in nickel prices and began smelting this stockpiled material in August 1989.

In November 1990, the company resumed mining on a limited basis to supplement the stockpiled feedstock. Ore from the reopened section on Nickel Mountain was averaging 1.18% Ni and was expected to last at least 3 years. At the beginning of 1991, negotiations were under way to open up two other sections of the deposit. The company spent \$2.5 million rehabilitating a dryer and crushing plant needed to treat the fresh ore. In 1991, Glenbrook mined 631,800 mt of ore containing 7,455 mt of Ni.⁸ The ore was used to produce 7,071 mt of Ni contained in ferronickel.

Glenbrook was in the process of doubling its ferronickel production capability to about 16,300 mt/yr of contained Ni. To meet the additional feed requirements, the company will not expand the mine, but instead import higher grade ore from New Caledonia. This decision was made after the company successfully processed an 18,140-mt shipment of New Caledonian ore in July 1991. Soc. Miniere du Sud Pacific has agreed to provide Glenbrook with 800,000 mt/yr of ore. The imported ore is expected to have a Ni content of 2.3%, significantly higher than the 1.0% to 1.25% material available at Nickel Mountain.

The New Caledonian ore was to be unloaded at rehabilitated dock facilities on Coos Bay, a lumber shipping port northwest of Riddle. The imported ore would be dried and crushed at the Coos Bay site and then trucked 137 kilometers (km) (85 miles) across the Coast Ranges to the smelter. Rehabilitation of the docks and construction of the dryer and crushing plant was scheduled to be completed by the fourth quarter of 1992. A shot casting facility was also being

built at the smelter as part of the project. The casting facility would allow Glenbrook to market 1/4-inch ferronickel shot in addition to the 28-lb ingots already being produced. The entire upgrading program was expected to cost \$33.0 million.

Black Hawk Mining Inc. was in the initial stages of developing a nickel-copper sulfide deposit near Warren, ME. The ore also contains significant amounts of cobalt. Formerly known as the Union or Crawford Pond deposit, its name was changed to the Knox deposit—after the name of the county. In 1990, Black Hawk spent \$400,000 on core drilling and metallurgical testing. The results indicate that the deposit contains 2.71 Mmt of resources grading 1.49% Ni, 0.69% Cu, and 0.12% Co for a cutoff grade of 1.1% Ni. In December 1990, the company began a feasibility study that included a mine and mill design as well as cost estimates.

Development of the Knox deposit had to be deferred until the State of Maine finished drafting new mining legislation that directly affected the project. In April 1990, the Maine Land Use Regulation Commission and the Maine Department of Environmental Protection were given the task of developing comprehensive rules for metallic mining in the State (Public Law 1990, Chapter 874). In late 1991, after months of public hearings and meetings, the two agencies finally approved Maine's first Metallic Mineral Exploration and Mining Rules. Black Hawk's next move was to apply for the environmental and mining permits required to bring the deposit into production.

Consumption and Uses

Western World nickel demand dropped slightly in 1991, following 6 years of continuous growth. Demand was estimated to be about 670,000 mt, down 3,000 mt from the record high set in 1990. Total U.S. apparent consumption decreased slightly because of a decline in scrap purchases. Both U.S. and world demand continued to be driven by the stainless steel industry, which accounted

for about 45% of nickel demand in the United States and more than 60% of world demand.

Production of raw stainless and heat-resisting steel in the United States slipped to 1.704 Mmt and was 8% lower than the corresponding figure for 1990.⁹ Nickel-bearing grades accounted for 71% of the production tonnage. Net shipments of all types of stainless totaled 1.314 Mmt. Shipments of sheets and strip amounted to 875,548 mt, breaking the record of 870,546 mt just set in 1990. The next largest category was plate (flat product 3/16 inch or more in thickness). Shipments of plate were 161,377 mt, down almost 14% from those of the previous year. Together, plate and sheet accounted for 79% of total net shipments, compared with 77% in 1990.

Stainless steel sheet is used in the manufacture of a wide range of consumer products, including household appliances, kitchen facilities, machinery, and medical equipment. In the past, automotive trim was an important end use for sheet, but aluminum and plastics have captured much of that market. Plate is primarily used in the fabrication of chemical reaction vessels and similar heavy-duty industrial equipment. The chemical, food and beverage, petrochemical, pharmaceutical, pulp and paper, and textile industries are all large consumers of stainless plate. The decrease in demand for plate was a direct result of cutbacks in spending on new and refurbished plants.

In 1991, U.S. consumption of primary nickel in superalloys decreased 4%. Part of the decrease was due to recessionary forces and weakening demand. However, the decrease was amplified by the increased availability and consumption of superalloy scrap.

In 1990, superalloy scrap was in relatively short supply. The 1990 shortage was the result of two factors. The first factor was that the London Metal Exchange (LME) cash price remained relatively high between 1988 and 1990, encouraging scrap dealers to turn around purchases as quickly as possible and keep stocks to a minimum. Nickel prices averaged more than \$6.00

per lb in 1988 and 1989, which quickly caused supplies of superalloy scrap to be depleted. The bulk of these supplies was never replaced. The second factor is that less scrap is being generated now because of the adoption of near net-shape-casting procedures. (See tables 3 through 5 and figure 1.)

Stocks

The combined stocks of primary nickel maintained in the United States by foreign producers and metal-trading companies with U.S. sales offices increased 46% during the year. At yearend, these stocks represented 34 days of apparent primary consumption. (See table 6.)

Markets and Prices

Nickel prices weakened significantly during the second half of 1991. The average LME cash price for the year was \$8,155.612 per mt, which equates to \$3.70 per lb. In terms of current dollars, this represented a drop of 8% from the 1990 average of \$8,864.100 per mt. The three principal reasons for the weakening were (1) slumping demand for stainless steel in several developed countries, (2) the increased availability of stainless steel scrap, and (3) improved productivity at primary production facilities.

In comparison to the past few years, the LME cash price was relatively stable. The weekly LME cash price began the year at \$8,388 per mt (\$3.80 per lb), gradually strengthened, and peaked at \$9,076 (\$4.12 per lb) at the end of March. In mid-May, the price, however, began to weaken. Some observers attributed the decline to a large increase in LME nickel stocks, which rose from 3,570 mt to 8,201 mt between April 30 and May 16. Several traders were also concerned at the time because (1) Falconbridge's smelter at Sudbury was running at only 40% of capacity because of a power failure and (2) Inco's labor contract was due to expire on May 31.

By August 2, the LME cash price had declined to \$8,165 (\$3.70 per lb). At that point, the rate of decline began to slow considerably, eventually reaching a

low for the year of \$7,068 (\$3.21 per lb) during the week of December 6. Uncertainty about supplies caused the price to recover slightly at the end of the year. The last weekly price (for the week ending December 27) was \$7,176 (\$3.26 per lb). The bid price on December 31 was \$7,170 (\$3.25 per lb).

The LME gave approval for three U.S. warehouses to hold nickel, beginning October 7, 1991. The warehouses were in Granite City, IL, Long Beach, CA, and Toledo, OH. The LME had already approved Baltimore, MD, and Bridgeport, CT, as U.S. warehouse sites in 1990. The Baltimore warehouse was operational in 1991 and, on January 6, 1992, had 24 mt of cathodes on hand from deliveries.

Accurately projecting demand for nickel, chromium, and some of the other strategic metals has been extremely challenging in recent years. One of the stumbling blocks in calculating apparent consumption has been a lack of concrete information about the content of strategic metals in different categories of scrap. To help in this area, the U.S. Bureau of Mines has published a study whose objective was to calculate an accurate, reliable estimate of the contents of chromium, nickel, and other metals in stainless and heat-resisting steels.¹⁰ In this study, IC 9275, the elemental fraction of stainless and heat-resisting steel was calculated as the ratio of the weight of element contained in stainless steel to the weight of stainless steel produced. The elemental fraction was calculated as a time-averaged, grade-averaged value, from 1962 through 1983, including the grades for which production was reported by the American Iron and Steel Institute.

The content data provided in IC 9275 is also helpful in certain life-cycle studies. Modeling the life cycle of different toxic metals is becoming increasingly popular as a means of attacking environmental problems. Unfortunately, determination of representative Ni contents for some of the more poorly tracked components in the life cycle of nickel continues to be a problem. Assigning Ni contents to different categories of stainless steel scrap

is particularly difficult. The IC methodology can be used to determine the average amount of Ni in different grades of stainless steel scrap. The average Ni content of all of the stainless steel produced over the past 20 years turned out to be 7% plus or minus 1%.

Foreign Trade

The U.S. net import reliance as a percentage of apparent consumption was 71% in 1991. The figure remains high, despite the resumption of primary production in Oregon, because of continuing strong demand for stainless steel in the United States. Imports accounted for about 95% of primary supply in 1991. Canada, as usual, supplied most of the imported material. A significant part of the nickel imported from Norway, the second largest source, was also of Canadian origin. Falconbridge's smelters have been shipping matte to Kristiansand, Norway, for refining since 1928. The refined products—principally metal granules, cathode, and crowns—are then exported to the United States for sale.

The high level of demand for primary nickel has also meant high demand for nickel-bearing scrap, both domestically and abroad. The processing of scrap accounted for the balance of domestic production. U.S. exports of stainless steel scrap remained strong in spite of weakening prices. The exported scrap contained an estimated 17,407 mt of Ni, about the same as that in 1990 but down somewhat from the 19,841 mt of 1989. These figures are based on the assumption that the scrap averaged 7.5% Ni during the 3-year period. (See tables 7 through 9 and figure 2.)

World Review

In June 1990, the International Nickel Study Group (INSG) met for the first time at The Hague, the Netherlands. The meeting climaxed 10 years of difficult negotiations and was followed by a second general session in April 1992 as well as several interim statistical meetings. The INSG has two primary

functions. The first function is to provide transparency by gathering, collating, and publishing statistical data on the international nickel market. The second is to provide an intergovernmental forum for discussion of issues of concern to nickel-producing and nickel-consuming countries. To date, Australia, Canada, the C.I.S., Japan, and 10 other nations have joined the INSG. The European Community also participates as a single entity. The United States and another five countries have been sending observers to the meetings.

The INSG has been publishing a monthly statistical bulletin since 1991. The first issues have included quarterly production and trade data for individual countries. Monthly data on LME nickel stocks and daily prices for the month were also being reported. The organization was preparing to publish a directory of worldwide nickel production facilities that may incorporate semi-annual short-term supply and demand forecasts.

Outokumpu Metals & Resources Oy (OMR), the Finnish nickel producer, and Mooney Chemicals Inc. of Cleveland, OH, merged their chemical businesses on September 30, 1991. A newly incorporated holding company, OM Group Inc. (OMG), now controls Mooney Chemicals Inc. as well as two OMR production units—Outokumpu Chemical Oy of Finland and Vasset S.A. of France. OMR believes that the merger will create a fully integrated global group with a high-technology base that can draw upon the long experience of its personnel in the nickel and cobalt chemical business.

Capacity.—The data in table 10 are rated capacity for mines, smelters, and refineries as of December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operation rate, based on the physical equipment of the plant, and given acceptable operating procedures involving labor, energy, materials, and maintenance.

Australia.—In mid-1991, OMR and Australian Consolidated Minerals Ltd. (ACM) decided to defer development of the Mount Keith deposit, 70 km northwest of Leinster and Agnew. The decision was taken after some of the Mount Keith ore was found to contain as much as 10% magnesia (MgO). Initial pilot plant tests had indicated much lower magnesia levels. If indeed true, the high magnesia content could make the ore difficult to smelt. Extensive testing was under way to confirm the preliminary findings.

The Mount Keith deposit contains an estimated 270 Mmt of sulfide ore averaging 0.6% Ni. Although the ore is considered low grade in terms of its Ni content, it is low in pyrrhotite. Pyrrhotite is undesirable because it follows the pentlandite into the concentrate, making smelting more difficult by raising already high sulfur levels even higher.¹¹ Because of the low pyrrhotite, tests have indicated that a high-purity, 20% Ni concentrate can be produced from the Mount Keith ore. The deposit is also near the surface and can be mined economically by open pit methods.

The original plan called for the Mount Keith concentrate to be shipped to Finland for processing into ferronickel. A new ferronickel facility was to have been built in Finland to handle the Australian concentrate while the mine was being developed. However, because of the magnesia, the mine will now be developed first. While the ferronickel facility is being redesigned, about 16,000 mt/yr of Ni contained in concentrate will be sent to existing facilities in Finland for processing first into matte and then refined nickel. An additional 9,000 mt/yr of Ni in concentrate will have to be sold on the world market until the new ferronickel facility can be completed.

Because of the delays at Mount Keith, OMR has decided to accelerate the development of its Forrestania nickel deposit north of Lake King. At the beginning of 1991, OMR owned 55% of the Forrestania deposit, with the balance split between Arimco N.L. and Cyprus Gold Australia Corp. Since then, the

Finnish company has bought out its two partners and decided to open the mine. Production was scheduled to begin in early 1993. Forrestania has 4.4 Mmt of ore reserves, enough to permit the mine to operate for at least 10 years. At full capacity, the mine should be able to produce 7,000 to 8,000 mt/yr of Ni in concentrates, all of which will go to OMR's smelter in Harjavalta, Finland.

Western Mining Corp. Holdings Ltd. (WMC), one of the four largest nickel producers in the Western World, seemed intent on gaining an even larger share of the global nickel market. The Australian company was employing a two-pronged strategy to achieve that end. In September 1991, it began expanding production capacity at its currently owned facilities from 54,000 mt/yr to 65,000 mt/yr. At the same time, the company started negotiating with ACM to purchase the Mount Keith deposit. The Mount Keith deposit was important to both WMC and OMR because it had very large reserves of nickel at a time when refinery feed had been tight.

WMC operates a smelter at Kalgoorlie and a refinery at Kwinana. Feed for the smelter comes from the company's mining complexes at Leinster and Kambalda. The capacity of the Kwinana refinery was in the process of being upgraded from 34,900 mt/yr to 42,000 mt/yr. Because smelter capacity will still exceed refinery capacity by about 20,000 mt/yr of contained Ni, some of the nickel will continue to be sold on the open market. The company was also planning to increase capacity at the Leinster Mine from 15,000 mt/yr of Ni in concentrate to about 35,000 mt/yr. However, plans to expand the Kambalda Mine and the Kalgoorlie smelter were on hold, pending the resolution of issues involving freight and power rates.

WMC's expansion program was tied to three company goals. All three goals required action on the part of the Government. The first goal, obtaining approval from Australia's Industrial Relations Committee for continuous mining at one of the Kambalda complex mines, has already been achieved. WMC had been running three 7½-hour shifts, 5

days per week. As a result of the approval, the company began around-the-clock mining in mid-August 1991. Approval seems certain to be granted at the other Kambalda mines. The second goal required a guarantee from the Western Australian Government that environmental standards would not make the expansion unprofitable. The third goal required the Government to set lower energy rates so that WMC could compete more effectively with other Western World nickel producers. The company had been negotiating with the Western Australian Government for 6 months in an attempt to lower energy costs. WMC asserted that moving its refinery to the State of Victoria would result in a 50% cut in energy costs.

Acquisition of the Mount Keith deposit was not easy. ACM held 100% of the equity in the project. To facilitate the takeover, WMC formed a joint venture with Normandy Poseidon Ltd. The jointly owned company, Resplendid Pty. Ltd., was to buy ACM outright. WMC would then take control of the Mount Keith deposit, while Normandy Poseidon would get ACM's copper, zinc, and gold assets. There would be no further association between WMC and Normandy Poseidon once the AMC assets were divided.

The day before the expected takeover, OMR disrupted WMC's plans by agreeing to purchase a 50% stake in Mount Keith for \$60 million. WMC, not willing to concede defeat, asked that ACM's shareholders receive full and timely disclosure of all relevant matters pertaining to the OMR agreement. WMC also requested that the ACM-OMR arrangement be discussed at a shareholder's meeting, at which time an independent analysis would be presented on the relative merits of the WMC and OMR proposals.

In the end, the largest group of ACM shareholders accepted the Resplendid takeover bid, and the balance of shareholders acquiesced. After the takeover, WMC and OMR, ACM's former partner in Mount Keith, signed an agreement to develop the project on a 50-50 basis. OMR was to receive 14,000

mt/yr of Ni in concentrate from Mount Keith instead of the 18,000 mt/yr it would have received under the original agreement with ACM. OMR was hoping to make up the deficit from its European operations and from future production from the Forrestania project. The original AMC-OMR plan called for the production of 28,000 mt/yr of Ni in concentrate. If this plan is adhered to, WMC would receive 14,000 mt/yr of nickel in concentrate, a substantial addition to its supplies of feedstock.

After the successful bid for control of Mount Keith, WMC also moved forward with its plans to expand the smelter at Kalgoorlie. The decision to expand the smelter was reached following an agreement with the Western Australian Government on sulfur dioxide emissions. The expansion at Kalgoorlie would enable the smelter to treat at least 65,000 mt/yr of Ni in concentrate produced from Leinster, Kambalda, and Mount Keith. In 1990, the smelter treated 55,700 mt of Ni in concentrate plus some high-grade nickel sulfide ores. Increased production at the smelter would require the installation of an additional oxygen plant. The materials handling facilities at the smelter would also be upgraded. The new oxygen plant was to be operational by late 1993.

WMC was also studying the feasibility of developing its newly acquired Bulong property, a nickel-cobalt laterite prospect 35 km east of Kalgoorlie. The company purchased a 70% interest in the Bulong deposit in 1990. The study was expected to take 5 years and would require the construction of a pilot plant. Proven and probable reserves were estimated at more than 90 Mmt of ore, grading 1.05% Ni and 0.07% Co.

Dominion Mining Ltd. was considering a joint venture with overseas companies to develop its Six Mile deposit near Yakabindie, again in Western Australia. The Six Mile deposit is about 25 km south of Mount Keith. Results to date have been extremely promising, but the project has been threatened by aboriginal claims that the mine should be blocked on environmental and cultural grounds. At yearend, the Parliament of Western

Australia was considering legislation that would override existing aboriginal heritage laws and allow the Yakabindie project to go forward. If the claims can be successfully thwarted, the deposit could be in production as early as 1994.

In September 1991, Dominion released the results of its final feasibility study and was hoping to begin mine construction sometime in 1992. The feasibility study indicated that, at a cutoff grade of 0.35% Ni, there is a measured and indicated recoverable resource of 96.4 Mmt of sulfide ore grading 0.504% Ni to a depth of 350 meters (m). Additional resources have been found 2 km to the south at the Golden North prospect.

The mine plan called for a 350-m-deep open pit mine producing about 6 Mmt/yr of ore for at least 12 years. The 6 Mmt of crude would result in the production of about 110,000 mt/yr of concentrate containing about 21,000 mt of Ni. The low-impurity, 18%-Ni concentrate could be sold to smelters and some refineries, or a roasted calcine could be produced, which could then be sold to stainless steel mills.

Queensland Nickel Pty. Ltd. imported about 13,000 mt of Ni in ore and concentrate from New Caledonia during the year. An additional 8,900 mt of Ni in ore and concentrate came from Indonesia. The material was being converted to nickel oxide (90% Ni) at the company's Yabulu hydrometallurgical refinery at Townsville. The ore was being unloaded at outmoded berths in the Port of Townsville and railed to Yabulu. About \$70 million was needed to upgrade the berths and handling equipment. Queensland Nickel had wanted to construct a new port facility at Halifax Bay, but environmentalists opposed the construction, fearing possible damage to the Great Barrier Reef. In June 1990, the Great Barrier Reef Marine Park Authority sided with the environmentalists and ruled against the project.

Shortly afterward, Dallhold Nickel Management Pty. Ltd., the principal partner in Queensland Nickel, began having financial difficulties. At that time, Queensland Nickel was a joint venture of Dallhold (72%) and Nickel Resources

North Queensland (28%), a limited partnership owned by the State of Queensland. On July 3, 1991, Dallhold's lenders—a banking syndicate led by the Hong Kong and Shanghai Corp.—took control of both the 24,000-mt/yr refinery and the venture's Greenvale Mine and had Dallhold put into receivership. The lenders then took steps to find a buyer for the 72% interest previously held by Dallhold and eventually approached Inco. Inco agreed in principle to acquire Dallhold's interest for between \$200 to 235 million, depending upon which assets were sold, but later tabled its offer. At yearend, Queensland Nickel was still being operated by the syndicate.

Agip Australia Pty. Ltd. has postponed development of its Radio Hill nickel-copper deposit in the Pilbara. The deposit, about 30 km south of Karratha, had combined proven and probable reserves of 1.0 Mmt of ore grading 2.5% Ni and 1.8% Cu. Production at the underground mine had been scheduled to begin in late 1992 and to continue for at least 7 years. Annual production would have been about 3,000 mt of Ni contained in matte. The facility was to have used Isamelt technology, developed jointly by MIM Holdings Ltd. of Queensland and an Australian Government-owned research organization. This would have been the first time that the technology would have been used for smelting ores other than those of lead and copper.

Botswana.—Bamangwato Concessions Ltd. (BCL), the Botswanan nickel producer, was to have received a loan from the European Community to improve productivity. The company was planning to use most of the money to deepen its Selebi and Phikwe Mines. Ore reserves on the existing levels were almost depleted. The deepening program would allow BCL to mine seams of higher grade ore and maintain existing production levels. BCL produced about 20,000 mt of nickel contained in matte in 1991. The matte was shipped to Falconbridge's operations in Norway for refining.

Brazil.—The Brazilian ferronickel producer, Cia. de Desenvolvimento de Recursos Minerais S.A. (CODEMIN), was planning to increase production 25% by installing a sinter plant at its Niquelandia complex. The sinter plant would increase the efficiency of the overall operation and extend the life of the mine from 20 years to 31 years. The complex is in the State of Goias and has a capacity of 8,000 mt of Ni in ferronickel.

Burundi.—The Government of Burundi was ready to conduct a \$4.4 million final feasibility study on its Musongati nickel deposits. A lack of infrastructure had made development uneconomic in the past, but a study completed in June 1990 indicated that commercial exploitation was now viable. The study concluded that recent improvements in Burundi's transportation system and energy generation capacity, together with planned further development in these sectors, would result in the necessary infrastructure being in place by the time mining began.

Canada.—Inco continued to expand mining operations in the Thompson nickel belt of Manitoba. The company was planning to spend \$248 million between 1991 and 1997 to develop the 1-D ore body and expand operations at the Birchtree Mine. Development of the 1-D ore body was launched during the year, with production scheduled to begin in 1992. A 5-km-long haulage tunnel was being constructed from the main shaft of the Thompson Mine to the 1-D ore body. By 1997, production was expected to reach 17,000 mt/yr of nickel.

Inco also announced the discovery of two nickel deposits in the Sudbury district of Ontario. The larger of the two, called Victor, is 25 km from Sudbury on the northeast rim of the Sudbury basin. Although Inco estimates that the deposit contains between 18 and 36 Mmt of ore grading 2.25% Ni and 7.3% Cu, it is unlikely to be exploited in the near future because it lies between depths of 2,460 and 2,770 m. The other deposit is only

925 m from Inco's existing McCreeley East Mine and is much more likely to be developed. The second deposit is estimated to contain about 7,300 mt of ore grading 0.8% Ni and 11% Cu between depths of 1,075 and 1,540 m.

Falconbridge Ltd. and Flag Resources Ltd., a Calgary-based company, have begun drilling the Wanapitie anomaly east of Levack. Exploration data suggest that the anomaly may be a world-class deposit rivaling that of the neighboring Sudbury Basin, one of the world's more productive and better known nickel deposits. The Wanapitie anomaly (named after a nearby lake) is both a gravitational and magnetic high, a good indicator of commercially valuable mineral deposits in the Precambrian terrain of Ontario. The anomaly is within a few kilometers of and roughly the same size and shape of the Sudbury anomaly, which underlies the Sudbury basin. Flag Resources, the second largest claim owner after Falconbridge, has held 536 claims in the area (approximately 24,000 acres or 9,700 hectares) since 1980. However, much of the surrounding area was off limits to mining until the spring of 1990 under an Indian Land Caution issued by the Canadian Government. Since then, Falconbridge has conducted an aeromagnetic study of the anomaly, staked numerous claims, and quickly became the largest holder in the area.

Falconbridge, Flag Resources, and the Teck Corp. of Vancouver, British Columbia, have staked out much of the western half of the Wanapitie anomaly, but the eastern half was still under an Indian Land Caution. Falconbridge has launched a 5-year drilling program, expected to cost \$3,750,000, to determine if significant amounts of nickel are associated with the anomaly. If Wanapitie turns out to be a world-class deposit similar to Sudbury, it would have major implications for nickel mining not only in Canada, but throughout the world. Mining companies holding claims on the anomaly would have access to a major new source of nickel ore that could be mined at relatively low cost. Many of the deposits in the Sudbury basin are depleted, and some of the mines there are

more than 1.5 km deep. Any deposits found in the Wanapitie anomaly would probably be closer to the surface, permitting open pit mining, at least initially. Surface mining is cheaper than underground mining and would give Falconbridge and the other two companies a competitive edge.

Falconbridge was also conducting a prefeasibility study of the Raglan deposit in northeastern Quebec. If the results of the study are mostly positive, mine construction could start as early as 1992, with production beginning in 1995 or 1996. Preliminary plans called for a production rate of 16,000 to 20,000 mt/yr of Ni in concentrate. The deposit is estimated to contain 17.7 Mmt of ore, grading 3.15% Ni and 0.88% Cu.

The deposit is on the northern tip of the Ungava peninsula where the waters of Foxe Channel mix with those of Hudson Strait. Development would almost certainly require the installation of on-site concentration equipment because of the Arctic location. The concentrates would probably be shipped to Falconbridge's smelter at Sudbury. Should the project come to fruition, the Raglan concentrate would supplement, but not replace, any of Falconbridge's Sudbury production. Output from the Sudbury smelter would rise accordingly. The major difficulty involved in developing the Raglan deposit is its remoteness and the absence of any local infrastructure.

On May 15, the number 1 furnace at Falconbridge's Sudbury smelter lost power when some electrical hardware failed. Partial power was reestablished 2 days later, but the smelter was still able to operate at only 40% of capacity because the number 2 furnace was shut down at almost the same time by an unrelated electrode failure. Mine production continued while repairs were being made, with ore being stockpiled on the ground. By September, Falconbridge had made up the lost production.

Sherritt Gordon Ltd. appears to have cut itself off from much of the world nickel market by importing Cuban feedstock. About 2,000 mt of what was labeled nickel oxide sinter and other immediate products from Cuba arrived in

Canada in the spring of 1991. The shipment reportedly consisted of mixed sulfide concentrates containing about 55% Ni and 5% Co. By the end of the year, a total of 10,700 mt of Cuban material had entered the country. Both Inco and Falconbridge publicly denied receiving the Cuban material. Sherritt has declined to comment on the origin of their feedstocks. By deduction then, the material almost certainly was being used by Sherritt as feedstock for its Fort Saskatchewan refinery in Alberta. The refinery lost 60% of its feed material when Inco decided not to renew its 10-year feedstock contract with Sherritt. The contract expired at the end of 1989, and Sherritt has since been seeking additional sources of feed. The shortage of feed forced Sherritt to close the refinery for 2 months in 1990 and played a role in the subsequent replacement of the company's board of directors.

Future marketing of Sherritt products may prove difficult. Europe, Japan, and the United States are the three largest nickel markets in the world, and all three have various restrictions on the importation of Cuban products. Sherritt could be precluded from selling into the U.S. market because of the trade embargo on Cuban material and materials of Cuban origin, which has been in effect since 1963. In Europe, the United States has bilateral agreements with France, Germany, Italy, and the Netherlands that regulate the export to the United States of nickel-bearing materials produced in those countries that contain more than 2.5% Ni. The agreements require that these materials contain no material of Cuban origin. The first three European countries are major stainless steel producers. A similar agreement exists between the United States and Japan, the world's largest nickel consumer. Sherritt's action appears to have placed the company in a position where it cannot sell to one major world market and is limited in the other two. These three markets previously accounted for more than one-half of Sherritt's sales.

Sherritt nickel could continue to be sold in the United States if the company decided to process its feedstock in

batches, thereby isolating the Cuban material. However, there is currently no bilateral agreement in effect with Canada, and thus no procedures established by which Canadian nickel-bearing products can be certified to be free of Cuban material. Accordingly, Sherritt nickel would not be allowed into the United States. Batch processing would also be inefficient and expensive. There has been speculation that Sherritt could remain in these markets by swapping with other producers to obtain nickel not of Cuban origin. That, too, is unlikely because the other producers would probably ask for a premium, making the swap uneconomical.

The deal makes sense from Cuba's point of view because Cuba would receive desperately needed hard currency for its nickel concentrates. Before the dissolution of the U.S.S.R., Cuban nickel-cobalt sulfides were refined at Orsk in the Urals as part of a barter arrangement. Sherritt may have had little choice but to acquire the Cuban material because of the tight supply of concentrate worldwide in recent years.

Timmins Nickel Inc. and BHP-Utah Mines Ltd. were considering dissolving their partnership in the Redstone Mine. Timmins has obtained an option to buy the 49% share held by BHP. The Redstone Mine at Timmins, Ontario, has been producing about 92,000 to 96,000 mt/yr of sulfide ore grading 2.32% Ni.

Colombia.—Cerro Matoso S.A. was planning to expand the capacity of its ferronickel smelter at Montelibano in Cordoba Province. The addition of a 12,000-mt/yr furnace would permit the facility to raise production from the current 20,000-mt/yr level to about 32,000 mt/yr. Present production was still below the 22,500-mt/yr limit of the smelter, but the company was expecting to operate at full capacity in 1993.

In a related matter, the Government of Colombia announced that a special export tax would be levied on oil, gas, and ferronickel producers. Cerro Matoso would have to pay the tax, even though it is a joint venture between Instituto de Fomento Industrial (an agency of the

Colombian Government) and Shell Oil Co. Ltd. The tax amounts to about 2.5 U.S. cents for every pound of contained nickel exported.

Cuba.—Reports indicate that Cuba plans to more than double its nickel production over the next 5 years after receiving major financial and technical aid from a western mining company. The plans call for \$1.2 billion to be invested in the island's nickel industry. New extractive technology and equipment would enable the Cubans to become more energy efficient and to produce higher purity nickel.

The Punta Gorda nickel refinery was closed in September 1990 as part of a number of energy-saving measures announced by the Cuban Government. Petroleum shipments from the former U.S.S.R., which accounted for more than 70% of Cuba's imports, had been falling increasingly behind schedule. Because Cuba had little foreign currency with which to purchase oil from Arab countries, its energy problems were compounded by the rise in oil prices during the Persian Gulf crisis. Punta Gorda was only one of the country's three nickel production facilities. The other two, at Moa Bay and Nicaro, were also affected by the problem to a smaller degree. The Moa Bay and Nicaro plants were operating significantly below their combined capacity of 44,500 mt/yr of Ni.

Punta Gorda resumed operations in April 1991. The refinery has three production lines, each a separate unit with a nominal capacity of 10,000 mt/yr. The first line had been operating normally, and the second was just coming on-stream after experiencing technical difficulties when the September shutdown occurred. The third line was apparently idle.

A fourth refinery was being built at Los Camariocas. However, construction of the 30,000-mt/yr Ni refinery may be delayed or even canceled as a result of the unification of Germany. Substantial support for the project was to have come from the former Government of the German Democratic Republic. The current German Government has declared

that all cooperative agreements between the former East German Government and Cuba are void. Production had been scheduled to start in 1993.

Finland.—In the fall of 1991, the Government of Finland approved a basic plan to privatize Outokumpu Oy and other state-owned companies. Since then, the Finnish parliament has given the government authority to decide on ownership structures, but no decision has been made on whether the Finnish State will actually relinquish its majority holding in Outokumpu. The Finnish State currently holds 57% of the stock in Outokumpu. The remaining 43% is owned by private Finnish investors and institutions.

During the summer, Outokumpu overhauled and expanded its Harjavalta smelter in Turku ja Pori Province.¹² About \$17 million was spent upgrading the facility and improving environmental conditions. As a result of the upgrading, sulfur dioxide emissions have been reduced 40%; metal in wastewater, more than 50%; and dust emissions, 30%.

In October 1991, the company's technology group bid on the modernization of the Pechenga nickel smelter over the border on the Kola Peninsula. The company submitted a tender of about \$600 million to the Norilsk Nickel Combine. (See section on the U.S.S.R.) Modernization would have reduced sulfur dioxide emissions to a fraction of their current level. The dissolution of the U.S.S.R. has prevented the start of financing negotiations, delaying the project. Financing was to have been provided by Nordic interests.

In 1990, OMR, the base metals subsidiary of Outokumpu Oy, signed an agreement with the former Karelian Autonomous Soviet Socialist Republic to develop the Republic's nickel-copper deposits. As part of the agreement, the Finnish nickel producer would evaluate a nickel-copper deposit in the Kivijarvi region of Russian Karelia, northeast of Aanisjarvi. The work would primarily involve geological and ore-dressing studies. If the deposit were developed,

Outokumpu could receive some feed for the company's Harjavalta plant.

Outokumpu Chemicals has slowly been increasing production of nickel-base inorganic chemicals. Nickel-base and cobalt-base chemicals are made along with fine cobalt powder at the company's plant in Kokkola, northeast of Vaasa on the Gulf of Bothnia. Between 1990 and 1991, output went from 1,644 mt of contained Ni to 1,790 mt. Expansion of the Kokkola plant was completed in late 1991, and production was scheduled to reach 5,000 mt by 1994.

Indonesia.—P.T. Inco had to temporarily shut down the No. 3 furnace at its South Sulawesi plant after one of the electrodes failed. The furnace was damaged by the ensuing electrical fire. The incident resulted in a production loss of 567 mt of nickel (in matte). However, the company was able to make up the tonnage before the end of the year. Inco Ltd. currently owns 58% of the Indonesian company.

Japan.—Sumitomo Metal Mining Co. Ltd. has begun constructing a state-of-the-art nickel refinery that employs new processing technology. The facility uses the Matte Chlorine Leach Electrowinning (MCLC) process, a refining technology developed by Sumitomo. The MCLC process proved successful when part of the company's Niihama cobalt refinery in Ehime Prefecture was converted to nickel refining in 1989. In 1990, the former cobalt facility produced 3,960 mt of nickel using the process. According to Sumitomo, the MCLC process is 30% more productive than conventional electrolytic refining methods.

The new refinery was expected to cost about \$60 million and would replace existing refining facilities at the Niihama plant site. Construction of the new 24,000-mt/yr plant began in late 1991 and was scheduled for completion in March 1993. The new refinery, together with the converted cobalt facility, would increase Sumitomo's refining capacity from about 22,200 mt/yr to at least 27,960 mt/yr. Sumitomo is Japan's only

producer of refined nickel and produced 22,230 mt of the metal in 1990. Sumitomo relies principally on P.T. Inco of Indonesia and WMC of Australia for its feedstock.

New Caledonia.—Societe Metallurgique le Nickel (SLN) shipped 38,469 mt of nickel in ferronickel, up from 35,216 mt in 1990. Twice in 1990, the French nickel producer was forced to declare force majeure on shipments from its ferronickel smelter at Doniambo. In December 1990, one of the smelter's three furnaces was seriously damaged by fire, destroying two of the furnace's transformers, but the company was able to successfully restore operations. The three furnaces have a combined capacity of about 40,000 mt/yr of Ni in ferronickel. The operation can also produce about 10,000 mt/yr of Ni in matte.

ERAMET-SLN, SLN's parent, has agreed to provide Nisshin Steel Co. Ltd. with ferronickel over the next 10 years. Nisshin, Japan's largest producer of cold-rolled sheet, will also acquire a 10% equity position in SLN. The 10% equity is in SLN's New Caledonian ferronickel operation, not ERAMET's refinery in France. The operation at Sandouville, near Le Havre on the English Channel, is set up to produce about 13,000 mt/yr of nickel metal and 3,000 mt/yr of nickel in salts from New Caledonian matte.

Under the terms of the agreement, shipments of Ni contained in ferronickel to Nissin from New Caledonia will increase from 1,500 mt/yr to 5,000 mt/yr. The deal will provide SLN with the financial means to expand the combined capacity of the Doniambo smelter from 47,000 mt/yr to 53,000 or possibly 55,000 mt/yr. It will also allow SLN to consider additional capacity as world demand for nickel grows.

Philippines.—Financial and marketing arrangements needed to bring the Surigao nickel mine and refinery on Nonoc Island back into operation were well under way. In late 1991, the Philippine Nickel Co. (Philnico) purchased the financially

troubled project from the Asset Privatization Trust. The project had been under the control of a parastatal company, the Nonoc Mining and Industrial Corp., for almost 8 years. The Philippine Government took control of the mine and refinery in August 1984 after the original operator, the Marinduque Mining and Industrial Corp., went bankrupt and was liquidated. The refinery had been idle since mid-1986.

The entire Nonoc rehabilitation project was expected to cost at least \$175 million. The International Finance Corp. (IFC), an affiliate of the World Bank, agreed to directly invest \$15 million in Philnico, loan the company \$35 million, and syndicate a loan for another \$80 million. A consortium led by Billiton Marketing and Trading BV has also signed an agreement with Philnico. The consortium was to take a \$15 million equity position in Philnico in return for exclusive marketing agreements. The remaining \$30 million would come from private investors.

If the Nonoc rehabilitation project were fully funded, production could resume as early as 1993. Full production would be about 25,000 mt/yr of nickel briquets and 2,500 mt/yr of Ni in nickel-cobalt sulfide concentrate. Billiton would market the briquets, while Outokumpu, another member of the consortium, would market the concentrate.

At yearend, Philnico had rehabilitated 8 of the plant's 14 roasters, all 8 thickeners, and 3 of 5 boilers.¹³ Three of 5 draglines were also made operational, along with 11 of the 18 75-short-ton dump trucks. Most of the trucks would eventually be replaced by a 6.3-km-long conveyor that would run from the mine to the plant.

Taiwan.—Tang Eng Iron Works, Taiwan's state-owned stainless steel producer, was expanding its production capacity from 130,000 to 260,000 mt/yr. The new capacity would be used to produce stainless steel bars and rods for the domestic market.

Tanzania.—Sutton Resources Ltd. has signed a comprehensive exploration and development agreement with the Government of Tanzania. The Vancouver-based company has been exploring for nickel in the Ngara district since 1990. To date, most of the work has focused on the Kabanga nickel-cobalt sulfide deposit close to the border with Burundi. The program will now be expanded north to include the Kagera region, which borders Rwanda and Uganda. The geology of the Kagera region reportedly resembles that at Thompson, Manitoba.

Geologists with the United Nations Development Program drilled the Kabanga deposit in 1979 and identified a zone of moderately high nickel-cobalt-copper mineralization associated with an ultramafic intrusive. The deposit is one of a string of magnetic anomalies extending for more than 8 km. In 1990, Sutton acquired the rights to the deposit and has conducted infill drilling to confirm the preliminary U.N. findings. According to company officials, the new drilling indicates that the Kabanga deposit contains between 230,000 and 350,000 mt of Ni, 19,000 to 33,000 mt of Co, and 38,000 to 54,000 mt of Cu.¹⁴ The sulfide zone may be near enough to the surface to allow open pit mining. The Ni content of the Kabanga ore ranges from 0.72% to 2.24%. The Co content varies from 0.07% to 0.12% and is sufficiently rich to be considered a coproduct.

U.S.S.R.—Outokumpu has offered to renovate the Pechenga nickel smelter on the Kola Peninsula for \$600 million. The company submitted a formal tender to the Norilsk Nickel Combine, the plant operator, in October 1991. The aging Pechenga smelter has been emitting 284,000 mt/yr of sulfur in the form of sulfur dioxide (SO₂). The Monchegorsk smelter on Lake Imandra emits a similar amount of SO₂. These large quantities of SO₂ reportedly have devastated large areas of the peninsula and caused damage to forests in neighboring Finland and Norway. The Scandinavian governments, particularly Finland, were becoming

increasingly anxious about deteriorating atmospheric conditions in the entire region. Reports indicate that the forests of northern Finland have perhaps only 10 years of life left if SO₂ emissions are not substantially reduced.

The Scandinavians were especially concerned about Pechenga because it is less than 50 km from the Norwegian port of Kirkenes and had been part of Finland until the end of World War II. The renovation of Pechenga would involve the conversion from electric furnaces to flash furnaces and the construction of a sulfuric acid plant. If Outokumpu's plan is accepted, the work would take 3 years to complete. The new furnaces would cut SO₂ emissions by about 95%. At yearend, financing of the project had still not been resolved. The dissolution of the U.S.S.R. has complicated and delayed startup of the financing negotiations. The financing of the renovation work at Monchegorsk was even more uncertain.

The Norilsk Nickel Combine currently controls 80% to 90% of the nickel sold by the newly formed C.I.S. The combine is responsible for nickel production at Norilsk in north-central Siberia as well as at Pechenga and Monchegorsk. Norilsk, the largest of the three complexes, lies between the Yenisey River and the western edge of the Putorana Plateau. In 1991, the Siberian operation had five underground mines and one open pit in operation. Both massive and disseminated sulfide ores were being mined at Norilsk. The complex has been producing about 200,000 mt/yr of Ni in concentrate along with significant amounts of cobalt, copper, and platinum group metals.

Production at Norilsk was temporarily halved in April when the workers struck the combine for better working conditions. The strike lasted only 8 days and ended when the workers were granted pay increases. Norilsk is a major production facility for the world, and a prolonged strike would have put upward pressure on LME prices.

In 1990, Norilsk Nickel was recognized as an independent supplier by the LME, which had previously accepted Soviet nickel registered only under the name of

Raznoimport, the Soviet state trading organization. The Norilsk combine is no longer associated with Raznoimport and was being represented in western Europe by Normaco AB, a joint trading venture with Axel Johnson Resources AB of Sweden. Newco AG, a Swiss trading company with ties to companies in southern Africa, reportedly was responsible for sales outside Europe.¹⁵ More than 110,000 mt of contained Ni was exported from the former U.S.S.R. in 1991.

A decree issued by the newly elected president of the Russian Republic reportedly allows local enterprises to keep more of their earnings than had been permitted in the past. Local industrial and manufacturing concerns, like Monchegorsk and Pechenga, would be allowed to sell 15% of annual production on the open market, with profits going directly to the plant. According to an official from the Monchegorsk plant, the extra revenue was desperately needed for the immediate installation of environmental protection equipment and, eventually, a new plant. To better understand the various retrofitting and renovation proposals, Russian and Finnish officials toured Outokumpu's smelter at Harjavalta after their preliminary discussions. The tour focused on the flash furnaces, which Outokumpu developed in response to increasingly demanding production schedules and emission control standards.

Venezuela.—Corporacion Federal de Minas (Cofeminas) was considering developing the Loma de Hierro nickel laterite deposit in the State of Miranda. The company, a 50-50 joint venture of Jordex Resources Inc. and Caracas Corp., is incorporated in Venezuela and has already received exploration and mining rights to the deposit. Jordex Resources is based in Vancouver, British Columbia. The Loma de Hierro deposit was investigated in the 1960's by the Venezuelan Ministry of Energy and Mines and contains an estimated 38 Mmt of ore grading 1.55% Ni and 0.05% Co. Cofeminas was planning to conduct additional drilling in 1992 and carry out

other activities needed to complete the feasibility study.

Yugoslavia.—The Kavadarci ferronickel production facility in south-central Macedonia was being rehabilitated and was scheduled to reopen in September 1992. Built in 1978 and closed in 1984 because of low nickel prices and high fuel costs, the facility was considered by most industry observers to be uneconomical to operate. The Yugoslavian Government, which had been running the plant, reportedly paid the facility's debts. If reopened, the plant was expected to produce only about 7,100 mt/yr of Ni in ferronickel, despite being rated at 16,000 mt/yr. At yearend, the situation was confused and chaotic because of the ensuing civil war.

At one point, the former Soviet Government had considered becoming a partner in Kavadarci. However, since then, many problems have developed in both Yugoslavia and the C.I.S. Industry observers doubt that a deal can be concluded with the new Russian Republic in the immediate future. Among other problems, the facility is thought to have a break-even point of \$4.25 per lb of nickel. The average annual LME cash nickel for 1991 was \$3.70 and will be considerably less in 1992. (See tables 11 and 12 for individual country data.)

Current Research

Advanced Batteries.—Automobile manufacturers around the world have been trying for more than a decade to develop an advanced battery to propel the electric cars of the 21st century. Impetus was added after the State of California passed environmental legislation in 1990 that put upper limits on future sales of gasoline-powered automobiles. At least 2% of the new automobiles sold in the State in 1998 must be "zero-emission" vehicles. This figure climbs to 10% by the year 2003. Nickel plays a prominent role in many of the latest battery prototypes, being preferable to lead in terms of lower density and environmental benignity.

In early 1991, the Big Three—Chrysler Corp., Ford Motor Co., and General Motors Corp.—formed a consortium to speed battery research. The Electric Power Research Institute (EPRI) and the U.S. Department of Energy (DOE) also joined the venture, now known as the United States Advanced Battery Consortium. In October 1991, DOE agreed to put up a total of \$130 million over the ensuing 4 years. A matching amount was to come from the four private partners.

At that time, the two top contenders were the sodium-sulfur battery and the nickel-metal hydride (Ni-MH) battery. The sodium-sulfur battery was pioneered by Ford and developed in Europe. The Ni-MH battery was less well known and was being developed by Energy Conversion Devices Inc. (ECD) in Troy, MI. The nickel-iron battery made by Eagle-Picher Industries, Inc. was reportedly too expensive for wide-scale passenger car use. An advanced nickel-cadmium (Ni-Cd) battery interested some researchers, but the consortium had strong concerns about its recyclability.

The consortium's first contract, worth \$18.5 million, eventually went to the Ovonic Battery Co. (OBC), a subsidiary of ECD.¹⁶ Ovonic was to build a prototype Ni-MH battery capable of propelling a compact car 300 miles (480 km) on a single charge. In addition, the battery would have to last 100,000 miles (160,000 km) and recharge in 15 minutes. With such a battery, the new electric car would be able to go from 0 to 60 miles (97 km) per hour in 8 seconds and have a top speed of 100 miles (161 km) per hour.

ECD originally developed the battery as a replacement for the small Ni-Cd batteries used in laptop computers and cellular telephones. The positive electrode is made of nickel hydroxide, while the negative electrode is an atomically disordered alloy of transition metals that absorbs large amounts of hydrogen during the charging part of the cycle. When the battery is discharging, hydrogen ions migrate out of the negative electrode into the liquid electrolyte,

where they react with negatively charged hydroxyl ions to form water.

The Ovonic battery has several advantages over its various competitors.¹⁷ First, the protons can penetrate into the interior of the sintered metal hydride electrode and are not restricted to the surface of the electrode, creating a relatively high energy density. Second, the battery can be charged much faster than its traditional lead-acid counterpart. Third, it is a sealed, maintenance-free unit that can withstand continuous overcharge. Fourth, the battery operates at room temperature unlike its sodium-sulfur contender. Finally, the nickel hydroxide electrode is free of toxic cadmium, making disposal and recycling of the battery less of a problem. In the conventional Ni-Cd battery, the negative electrode is made of cadmium. Cadmium is also incorporated in the positive nickel hydroxide electrode of some Ni-Cd units to reduce electrode swelling. The negative metal hydride electrode in the Ovonic battery, in contrast, is composed of chromium, nickel, titanium, vanadium, and zirconium—all of which are less toxic than cadmium and lead.

According to the Cadmium Association, growth in Ni-Cd batteries is running at 15% in Japan, while declining in Canada and the United States. Part of the decline in North America may be explained by the growing popularity of Ni-MH batteries that have nearly twice the capacity of their Ni-Cd counterparts. Part may be due to growing concerns about the disposal and recycling of batteries containing cadmium. The Ni-Cd batteries do have some pluses. At the present time they are less expensive and more tolerant of overcharging than the Ni-MH's.¹⁸ At least 23 U.S. companies were marketing the new portable Ni-MH batteries besides OBC. The list includes Duracell Inc., Eagle-Picher, Gates Energy Products Inc., Panasonic Industrial Co., and Sanyo Energy (USA) Corp.

Several Japanese companies were also heavily involved in battery research. Ni-MH batteries have been developed and were being marketed by Matsushita Battery Industrial Co. Ltd. and Sanyo

Electric Co. Ltd. Matsushita was reportedly producing about 500,000 units per month at its Shonan plant in Kanagawa Prefecture and was planning to expand output to 2 million per month. The new battery, which will be used in video cameras, laptop computers, and other electronic equipment, reportedly has twice the energy density of an equivalent Ni-Cd battery and can be recharged much faster. Sanyo's production was being sold to Motorola Inc. and Toshiba Corp.

Stainless Steel.—Austenitic stainless steel has been gaining increasing acceptance as an architectural material in recent years. Stainless was still an architectural novelty when it was chosen for the dome and gargoyles of New York City's Chrysler Building back in 1929. Since then, the material has won wide respect because of its durability, corrosion resistance, and maintenance-free surface. The new Canary Wharf Tower in London contains more than 1,200 mt of stainless, with at least one-half being austenitic S-31603 cladding [10% to 14% Ni plus 2% to 3% molybdenum (Mo)].¹⁹ Prefabricated, semidetached homes constructed of stainless steel and glass were being evaluated by the Delft City Council in the Netherlands as a low cost solution to their housing problem,²⁰ and at least two prototype stainless apartment buildings have been built in Paris. A 21-m-tall spire of austenitic S-30400 tops the 272-m-high Society Tower in Cleveland, while the minaret and two domes of the new Bait-ul-Islam Mosque in Toronto are clad with 0.4-mm-thick Erzeform 35 sheet containing 7% to 9% Ni.

In Western Australia, stainless steel mesh has been marketed under the name "Termi-Mesh" as a foundation barrier against termites since 1989. Termites can seriously damage a structure, especially in arid environments where buildings seldom have basements. When a new home is to be constructed directly on a concrete slab, the mesh is installed over the sand pad and covered with a waterproof membrane. The slab is then poured on top of the membrane.

OUTLOOK

Between 1981 and 1991, demand for nickel in the Western World grew at an average rate of almost 4% per year. However, demand began to slow in early 1991 as recessionary forces spread from North America to Western Europe and eventually to Japan. Since then, the economic restructuring of Russia and other members of the C.I.S. has allowed stocks of cathode and metal powder originally allocated to the Soviet defense industry to be exported to the West.

The arrival of the C.I.S. material came at a time when Western nickel demand was already weakening, causing LME stocks to build up to excessive levels. By December 1992, the LME warehouse in Rotterdam held more than 61,500 mt of nickel—a month's supply for the entire West. Export controls imposed by the new Russian Government were expected to slow the flow of cathode, but some smuggling will inevitably continue until the ruble stabilizes. Exports of cathode and nickel alloys masquerading as scrap will be especially difficult to control. The push to export is being driven by two forces. First, demand for stainless within the C.I.S. has been declining since 1989. Second, a large disparity still exists between internal nickel prices and the LME cash price. In January 1991, nickel was being sold in the former U.S.S.R. for about \$100 per mt, at a time when the LME price was about \$8,000 per mt. This gap has narrowed considerably since then. By July 1992, the internal price appeared to have skyrocketed to \$3,000 per mt, but the gap was still huge.

The global slowdown in economic activity and large LME stocks put pressure on nickel prices in 1992, triggering a slide in the third quarter. During the first half of 1992, the monthly LME cash price had been relatively stable, ranging from \$7,193 to \$7,862 per mt (\$3.26 to \$3.57 per lb). But, by October, the price had fallen below \$6,614 (\$3.00), the break-even point for some marginal producers and a psychological barrier for others. At one point in mid-November, the price was as

low as \$5,275 (\$2.39). By yearend, it had recovered somewhat after Inco, Falconbridge, Sumitomo, and several other producers announced cutbacks in output for 1993. The LME cash price is expected to range between \$5,000 (\$2.27) and \$7,500 (\$3.40) in 1993. The lower limit will be determined by the willingness of producers to retain market share by selling below cost. The upper limit will be a measure of the eagerness of the Norilsk Nickel Combine to earn hard currency and secure a permanent sales position in the West. Prices could conceivably return to 1990 levels in 1994 if Japan were to emerge from its current recession and increase stainless production. The Diet—Japan's national parliament—was planning to spend \$86 billion on public works to stimulate the Japanese economy, starting in 1993.

Austenitic stainless steel will continue to drive world nickel demand for both the short term (1993-95) and mid-term (1996-98). Japan is expected to be the dominant austenitic producer for the rest of the century and will continue to rely heavily on Australia, Indonesia, New Caledonia, and the Philippines for nickel matte and mine products. Japan is also the largest consumer of stainless of all types on a per capita basis. In recent years, Japanese stainless production has been 1.4 to 1.9 times greater than that of the United States. U.S. stainless production peaked in 1988 at 1.996 Mmt and has since been running between 1.70 and 1.85 Mmt.

Western demand for austenitic stainless in 1993 should be slightly less than the record high of 1990 because of the Japanese recession. The rest of East Asia will continue expanding stainless production capacity, although perhaps at a somewhat reduced pace. Little or no growth is planned for Western Europe, which accounted for 36% of the 12.4 Mmt of stainless (both austenitic and ferritic grades) produced worldwide in 1991. The Republic of Korea is already making more stainless than either Sweden or the United Kingdom, while Taiwan is hard on the heels of Finland, which currently ranks eighth in Western Europe. Consumption of stainless by end use is

also shifting. Decreased demand in traditional areas such as automobile wheel covers will be partially offset by new uses such as state-of-the-art pollution control equipment. Nickel consumption in stainless plate, the bright spot in 1990, may decline temporarily because growth in the capital goods sector is expected to remain sluggish for the next 2 or 3 years.

The long-term (1999-2002) forecast is much more rosy. If the past is any guide to the future, world stainless steel production should grow on the average 3% to 5% per year over the next 10 years. Total nickel consumption should grow at an even faster rate because stainless currently accounts for only 60% of total nickel demand and many novel, nonsteel uses are being developed for the element. The successful revitalization of Russia and the rest of Eastern Europe, coupled with a restructuring of the Chinese economy, could generate unprecedented demand for nickel at the turn of the century.

A significant amount of nickel also goes into superalloys. In the United States, much of this material ends up either in jet turbine engines or in sophisticated chemical processing equipment such as chemical reactors and pumps. Record numbers of orders for civil aircraft are expected to materialize sometime after 1995 because air traffic is steadily increasing and aging fleets need to be replaced. Demand for nickel by U.S. superalloy producers will probably be flat until then. Many domestic airlines are currently experiencing financial difficulties brought on by the recession, Government deregulation, new environmental controls, and escalating costs for jet fuel, but should be able to overcome these problems in time. The sluggish U.S. economy and the slowdown in Europe and Japan have discouraged chemical manufacturers from building new plants. Chemicals companies around the world are currently restructuring, downsizing, and making strategic alliances to penetrate previously closed markets. Orders for new chemical plants and equipment will continue to be weak through 1994, but the situation should change dramatically after Germany

finalizes reunification and Japan escapes from recession. The long-term outlook for superalloys is optimistic.

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TABLE 1
SALIENT NICKEL STATISTICS

(Metric tons of contained nickel unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Mine production	—	—	—	330	5,523
Plant production	—	—	347	3,701	7,065
Secondary recovery from purchased scrap:					
From ferrous scrap	24,718	37,682	32,293	27,399	25,231
From nonferrous scrap	7,613	3,357	7,492	6,317	7,289
Exports:					
Primary (nickel content)	³3,995	⁴5,561	⁴4,242	⁴8,873	9,104
Secondary (nickel content)	16,956	22,355	²7,218	28,184	27,798
Imports for consumption:					
Primary (nickel content)	134,511	140,039	¹118,543	131,115	132,445
Secondary	NA	5,884	9,137	11,634	6,212
Consumption:					
Reported:					
Primary	¹115,188	¹110,412	⁹95,406	¹110,585	98,631
Secondary (purchased scrap)	32,331	41,038	39,785	33,715	32,520
Apparent:					
Primary	¹140,146	¹132,774	¹116,533	¹124,975	125,443
Secondary (purchased scrap)¹	15,642	²23,919	²21,508	17,741	11,756
Stocks, yearend:					
Government	33,761	33,760	33,760	33,760	33,760
Producer	6,191	6,960	⁶6,326	⁸8,065	11,794
Consumer:					
Primary	9,505	10,441	⁹9,189	⁸8,419	9,653
Secondary	3,969	4,618	4,813	4,236	z3,414
Employment, yearend:					
Mine	—	—	—	12	8
Smelter	—	—	245	300	277
Price, cash, London Metal Exchange, per pound	\$2.19	\$6.25	\$6.05	\$4.02	\$3.70
World: Mine production	⁸890,539	⁹917,717	⁹970,493	⁹937,173	922,944

¹Revised. NA Not available.

²Secondary exports were included in apparent consumption for the first time in 1988.

TABLE 2
TIME-PRICE RELATIONSHIPS
FOR NICKEL

Year	Average annual price, dollars per pound	
	Actual price	Based on constant 1987 dollars¹
1940	0.35	3.16
1945	.32	2.36
1950	.45	2.20
1955	.66	2.83
1960	.74	2.81
1965	.79	2.73
1970	1.29	3.61
1971	1.24	3.27
1972	1.35	3.40
1973	1.49	3.53
1974	2.00	4.35
1975	1.87	3.69
1976	2.08	3.87
1977	2.04	3.55
1978	1.89	3.07
1979	2.96	4.42
1980	2.96	4.05
1981	2.71	3.38
1982	2.18	2.56
1983	2.18	2.46
1984	2.16	2.36
1985	2.26	2.39
1986	1.76	1.82
1987	2.19	2.19
1988	6.25	6.05
1989	6.05	5.62
1990	4.02	3.59
1991	3.70	NA

NA Not available.

¹Constant dollar price determined from gross domestic product implicit price deflator.

TABLE 3
NICKEL RECOVERED FROM PURCHASED SCRAP IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons of contained nickel)

	1989	1990	1991
KIND OF SCRAP			
Aluminum-base	210	209	¹ 1,464
Copper-base	3,270	3,084	2,329
Ferrous-base	32,293	27,399	25,231
Nickel-base	4,012	3,024	3,496
Total	39,785	²33,715	32,520
FORM OF RECOVERY			
Aluminum-base alloys	210	209	¹ 1,464
Copper-base alloys	4,895	4,437	3,709
Ferrous alloys	32,347	27,445	25,279
Nickel-base alloys	2,333	1,624	2,068
Total	39,785	33,715	32,520

¹Increase reflects additional data, which are not available for prior years.

²Data do not add to total shown because of independent rounding.

TABLE 4
REPORTED U.S. CONSUMPTION OF NICKEL, BY FORM

(Metric tons of contained nickel)

Form	1987	1988	1989	1990	1991
Primary:					
Ferronickel	15,801	¹ 11,741	10,163	17,354	13,945
Metal	² 87,854	² 88,694	² 75,828	² 81,993	74,220
Oxide and oxide sinter	9,005	² 7,028	5,883	5,578	3,218
Chemicals ¹	² 663	² 755	² 1,260	² 1,155	1,298
Other	¹ 1,865	² 2,194	² 2,275	² 4,504	5,950
Total primary²	¹115,188	¹110,412	²95,406	¹110,585	98,631
Secondary (scrap)³	32,331	41,038	39,785	33,715	32,520
Grand total²	¹147,519	¹151,451	¹135,190	¹144,300	131,151

¹Revised.

¹Metallic nickel salts consumed by plating industry are estimated.

²Data may not add to totals shown because of independent rounding.

³Based on gross weight of purchased scrap consumed and estimated average nickel content.

TABLE 5
U.S. CONSUMPTION OF NICKEL IN 1991, BY USE

(Metric tons of contained nickel)

Use	Commercially pure nickel	Ferronickel	Nickel oxide	Nickel salts	Other forms	Total primary	Secondary (scrap)	1991 Grand total	1990 Grand total
Cast irons	498	W	W	W	158	656	414	1,070	*1,473
Chemicals and chemical uses	1,213	—	52	W	—	1,265	—	1,265	1,156
Electric, magnet, expansion alloys	431	—	—	—	W	431	48	479	47
Electroplating (sales to platers)	11,173	—	—	232	4	11,409	—	11,409	*12,466
Nickel-copper and copper-nickel alloys	3,662	W	W	—	W	3,662	2,900	6,562	*7,130
Other nickel and nickel alloys	14,857	W	W	—	94	14,951	2,662	17,613	*17,235
Steel:									
Stainless and heat-resistant	18,728	13,722	3,165	W	4,061	39,676	24,381	64,057	*74,564
Alloys (excludes stainless)	4,997	223	W	—	W	5,220	436	5,656	*7,358
Superalloys	14,886	—	1	—	W	14,887	215	15,102	*15,877
Other ¹	3,775	W	W	1,066	1,633	6,474	1,464	7,938	*6,995
Total reported by companies canvassed	74,220	13,945	3,218	1,298	5,950	98,631	32,520	131,151	*144,300
Total all companies, apparent	XX	XX	XX	XX	XX	XX	11,756	137,199	142,716

¹Revised. W Withheld to avoid disclosing company proprietary data; included with "Other." XX Not applicable.
¹Includes batteries, ceramics, and other alloys containing nickel.

TABLE 6
NICKEL IN CONSUMER STOCKS IN THE UNITED STATES, BY FORM

(Metric tons of contained nickel)

Form	1987	1988	1989	1990	1991
Primary:					
Ferronickel	704	1,379	1,884	991	1,361
Metal	7,532	6,822	*5,340	*6,755	6,951
Oxide and oxide sinter	903	1,795	1,244	288	997
Salts	178	192	*333	*173	166
Other	187	252	*388	*212	178
Total primary	9,505	10,441	*9,189	*8,419	9,653
Secondary (scrap)	3,969	4,618	4,813	4,236	3,414
Grand total	13,475	15,058	*14,002	*12,655	13,067

¹Revised.

TABLE 7
U.S. EXPORTS OF NICKEL PRODUCTS, BY CLASS

(Metric tons of contained nickel and thousand dollars)

Class	1988		1989		1990		1991	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Unwrought:								
Primary:								
Cathodes, pellets, briquets, and shot	1,760	19,344	885	10,861	887	7,913	650	5,332
Electroplating anodes	187	1,618	NA	NA	NA	NA	NA	NA
Ferronickel	—	—	210	949	1,725	5,358	1,140	5,590
Powder and flakes	522	8,184	600	12,111	694	10,744	606	10,312
Oxide sinter	(¹)	(¹)	531	2,709	4,073	8,454	5,064	14,018
Chemicals:²								
Catalysts	960	21,745	1,344	34,875	1,202	40,138	1,224	49,145
Salts	2,132	23,785	674	8,982	292	4,440	420	6,962
Total³	5,561	74,676	4,242	70,487	8,873	77,047	9,104	91,359
Secondary:⁴								
Stainless steel scrap	16,557	239,807	19,841	320,683	17,472	212,368	17,407	196,380
Waste and scrap	5,798	36,079	7,377	45,739	10,712	49,355	10,391	47,025
Total³	22,355	275,886	27,218	366,422	28,184	261,723	27,798	243,405
Grand total	27,916	350,562	31,460	436,909	37,057	338,770	36,902	334,764
Wrought:								
Bars, rods, profiles, and wire	NA	NA	256	4,399	181	1,786	206	2,242
Sheets, strips, and foil	NA	NA	220	4,107	224	3,102	106	2,382
Tubes and pipes	NA	NA	61	3,445	61	1,049	42	1,132
Total³	NA	NA	537	11,951	465	5,937	354	5,756

¹Revised. NA Not available.

²For years prior to 1989, export data for nickel oxide sinter were included with those of salts.

³For the different salts, the nickel contents are assumed to be as follows: chlorides (25%), sulfates (22%), other salts (22%), oxide and oxide hydroxides (65%). The typical catalyst is assumed to have a nickel content of 22%.

⁴Data may not add to totals shown because of independent rounding.

⁵The nickel content of waste and scrap is assumed to be 50.0%, while that of stainless steel has been shown to be about 7.5%.

Source: Bureau of the Census.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF NICKEL PRODUCTS, BY CLASS

(Metric tons of contained nickel¹ and thousand dollars)

Class	1989		1990		1991	
	Quantity	Value	Quantity	Value	Quantity	Value
Unwrought:						
Primary:						
Cathodes, pellets, briquets, and shot	93,315	1,148,087	104,501	910,544	102,160	844,670
Ferronickel	11,476	117,630	14,273	116,484	14,547	113,267
Flakes	56	570	8	53	(²)	1
Oxide sinter ³	224	3,052	873	8,294	4,446	36,903
Powder	10,442	121,416	9,126	91,179	8,912	86,011
Chemicals:						
Catalysts	960	30,687	901	34,163	1,014	26,635
Salts	2,070	25,077	1,433	16,917	1,366	16,049
Total	118,543	1,446,519	131,115	1,177,634	132,445	1,123,536
Secondary:						
Stainless steel scrap	3,997	29,826	7,661	31,284	2,478	23,139
Waste and scrap ⁴	5,140	78,089	3,973	46,764	3,734	35,499
Total	9,137	107,915	11,634	78,048	6,212	58,638
Grand total	127,680	1,554,434	142,749	1,255,682	138,659	1,182,174
Wrought:						
Bars, rods, profiles and wire	386	7,739	600	7,963	669	8,323
Sheets, strip and foil	327	5,973	350	5,228	322	4,969
Tubes and pipes	113	2,799	84	2,304	140	3,588
Total	826	16,511	1,034	15,495	1,131	16,880

¹Revised.
²The nickel contents are as follows: oxide sinter from Australia, 90%; elsewhere, 77%. The salts category contains the following: chemical-grade oxide, 65%; chloride, 25%; sulfate, 22%; and other salts, which are assumed to be 22% nickel. Waste and scrap is assumed to be 50% nickel and stainless steel scrap 7.5% nickel.

³Less than one-half unit.

⁴Includes metallurgical-grade oxide only; chemical-grade oxide is included with salts.

⁵This import category is now listed in terms of its nickel content; in previous years, it was listed in terms of gross weight.

⁶Data do not add to total shown because of independent rounding.

Sources: Bureau of the Census and Journal of Commerce.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF NICKEL PRODUCTS IN 1991, BY COUNTRY

(Metric tons of contained nickel¹)

Country	Cathodes, pellets, and briquets, (unwrought)	Powder and flakes	Ferronickel	Oxide sinter ²	Waste and scrap	Stainless steel scrap	Salts and catalysts	Total	
								Wrought nickel ³	1990
Australia	8,409	801	—	4,059	2	—	—	13,271	9,206
Belgium	—	1	—	3	26	13	332	375	731
Canada	60,564	7,083	—	385	1,732	1,428	554	71,746	80,626
Colombia	—	—	2,040	—	—	28	—	2,068	2,698
Dominican Republic	—	—	7,904	—	8	2	—	7,914	8,756
Finland	524	—	—	—	—	—	268	791	1,728
France	1,455	(⁴)	300	—	266	—	190	2,211	2,273
Germany	256	5	—	(⁴)	595	2	230	1,089	787
Japan	(⁴)	(⁴)	(⁴)	—	25	(⁴)	322	12	432
New Caledonia	18	—	2,437	—	—	—	—	2,455	2,766
Norway	23,502	—	—	—	24	(⁴)	8	23,534	21,928
South Africa, Republic of	1,605	580	48	—	—	—	64	2,296	2,136
United Kingdom	227	300	—	—	637	32	66	1,261	1,255
Zimbabwe	2,968	—	—	—	(⁴)	—	—	2,968	3,588
Other	2,633	141	1,818	—	419	974	346	6,332	3,839
Total ⁴	102,160	8,912	14,547	4,446	3,734	2,478	2,380	138,659	142,749

¹The nickel contents are as follows: oxide sinter from Australia, 90%; elsewhere, 77%. The salts category contains the following: chemical-grade oxide, 65%; chloride, 25%; sulfide, 22%; and other salts, which are assumed to be 22% nickel. Waste and scrap is assumed to be 50% nickel and stainless steel scrap 7.5% nickel.

²Includes metallurgical-grade oxide only; chemical-grade oxide is included with salts and catalysts.

³Not included in "Total."

⁴Data may not add to totals shown because of independent rounding.

⁵Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 10
**NICKEL: WORLD ANNUAL MINE AND PLANT PRODUCTION
 CAPACITY, BY COUNTRY, DECEMBER 31, 1991**

(Thousand metric tons contained nickel)

Country	Mine capacity	Refinery and smelter ¹ capacity
North America:		
Canada	205	155
United States	5	250
Total	210	205
South America:		
Brazil	24	19
Colombia	22	23
Total	46	42
Caribbean:		
Cuba	54	30
Dominican Republic	33	32
Total	87	62
Europe:		
Albania	10	5
Austria	—	6
Czechoslovakia	—	16
Finland	11	19
France	—	16
Germany	—	3
Greece	23	27
Norway	—	55
U.S.S.R.	300	300
United Kingdom	—	45
Yugoslavia	28	28
Total	372	520
Africa:		
Botswana	25	—
South Africa, Republic of	45	29
Zimbabwe	18	18
Total	88	47
Asia:		
China	36	27
Indonesia	64	5
Japan	—	112
Korea, Republic of	—	12
Philippines ²	41	32
Taiwan	—	10
Total	141	198
Oceania:		
Australia	75	54
New Caledonia	91	45
Total	166	99
World total	1,110	1,173

¹Because matte is an intermediate product that must be refined before the nickel it contains can be used in making alloys or other product, smelter capacity for matte is not listed to avoid double counting.

²Standby or partially standby capacity.

TABLE 11
NICKEL: WORLD MINE PRODUCTION, BY COUNTRY¹

(Metric tons of nickel content)

Country	1987	1988	1989	1990	1991*
Albania (content of ore) ²	9,200	10,100	11,200	8,800	7,500
Australia (content of concentrate)	74,554	62,358	67,041	67,000	69,000
Botswana (content of ore milled) ²	25,900	26,000	23,700	23,200	22,500
Brazil (content of ore)	22,092	18,677	18,826	18,788	23,000
Burma (content of speiss)	50	104	184	80	100
Canada ³	189,086	198,744	200,900	199,400	192,821
China ²	25,000	25,000	25,000	27,000	27,500
Colombia (content of ferroalloys)	19,324	16,669	16,954	18,425	18,000
Cuba (content of oxide, sinter, sulfide)	33,824	41,758	44,200	40,000	35,400
Dominican Republic	32,521	29,345	31,264	28,700	25,000
Finland (content of concentrate)	10,557	11,700	10,480	11,524	8,500
Germany: Eastern states ²	1,800	1,500	1,500	900	500
Greece (recoverable content of ore) ²	9,202	13,131	16,097	15,700	15,700
Indonesia (content of ore)	57,764	57,982	62,987	68,308	69,000
New Caledonia (recoverable content of ore) ²	56,850	67,700	98,500	89,000	91,500
Norway (content of concentrate) ²	496	500	2780	23,100	2,200
Philippines	7,819	10,349	15,380	15,818	18,400
Poland (content of ore)	—	—	—	—	—
South Africa, Republic of	34,300	34,800	34,000	30,000	30,000
U.S.S.R. (content of ore) ²	270,000	280,000	280,000	260,000	250,000
United States (content of ore shipped)	—	—	—	330	5,523
Yugoslavia (content of ore) ²	3,900	3,900	4,000	3,800	3,500
Zimbabwe (content of concentrate) ^{2,4}	6,300	7,400	7,500	7,300	7,300
Total	890,539	917,717	970,493	937,173	922,944

*Estimated. ²Revised.

¹Insofar as possible, this table represents recoverable mine production of nickel. Where actual mine output is not available, data related to a more highly processed form have been used to provide an indication of the magnitude of mine output and this is noted parenthetically or by a footnote following the country name. Table includes data available through May 29, 1992.

²Reported figure.

³Refined nickel and nickel content of oxides and salts produced, plus recoverable nickel in exported matte and speiss.

⁴Estimates are based on metal production after deduction for nickel content of matte imported from Botswana for processing.

TABLE 12
NICKEL: WORLD PLANT PRODUCTION, BY COUNTRY AND PRODUCT¹

(Metric tons of nickel content)

Country ² and product	1987	1988	1989	1990	1991 [*]
Albania: Metal [*]	<u>2,500</u>	<u>2,500</u>	<u>2,500</u>	<u>2,000</u>	<u>2,000</u>
Australia:					
Metal	24,629	23,000	24,000	25,000	25,000
Oxide	19,900	19,000	20,000	20,000	20,000
Total	<u>44,529</u>	<u>42,000</u>	<u>44,000</u>	<u>45,000</u>	<u>45,000</u>
Brazil: ³					
Ferronickel	9,739	9,216	9,446	8,847	9,000
Metal	4,123	3,885	4,028	4,168	4,000
Total	<u>13,862</u>	<u>13,101</u>	<u>13,474</u>	<u>13,015</u>	<u>13,000</u>
Canada:					
Metal	110,785	114,845	103,963	90,900	80,000
Oxide	20,715	39,139	38,010	30,300	25,000
Total	<u>131,500</u>	<u>153,984</u>	<u>141,973</u>	<u>121,200</u>	<u>105,000</u>
China: Metal [*]	22,500	24,700	25,600	27,000	27,500
Colombia: Ferronickel	19,324	16,669	16,954	18,425	19,000
Cuba: Oxide ⁴	17,400	24,100	26,500	21,100	20,000
Czechoslovakia: Metal [*]	3,800	3,800	3,800	2,970	2,500
Dominican Republic: Ferronickel	<u>29,501</u>	<u>29,345</u>	<u>31,264</u>	<u>28,700</u>	<u>29,100</u>
Finland:					
Chemicals	1,130	1,573	1,953	1,643	2,190
Metal	15,392	15,721	13,355	16,882	13,850
Total	<u>16,522</u>	<u>17,294</u>	<u>15,308</u>	<u>18,525</u>	<u>16,040</u>
France:					
Chemicals	1,200	1,400	1,400	1,090	1,000
Metal	7,500	8,800	8,600	8,800	7,700
Total	<u>8,700</u>	<u>10,200</u>	<u>10,000</u>	<u>9,890</u>	<u>8,700</u>
Germany: Eastern states, metal [*]	3,100	2,600	2,700	1,300	725
Greece: Ferronickel	9,202	13,131	16,097	16,200	15,700
Indonesia: Ferronickel	<u>1,683</u>	<u>4,905</u>	<u>4,964</u>	<u>5,005</u>	<u>5,000</u>
Japan:					
Ferronickel	49,405	57,556	62,834	56,474	68,045
Metal	21,397	19,961	21,938	22,274	23,658
Oxide	22,475	24,744	21,444	21,500	25,000
Total	<u>93,277</u>	<u>102,261</u>	<u>106,216</u>	<u>100,248</u>	<u>116,703</u>
Korea, Republic of: Metal	—	—	4,173	5,987	11,340
New Caledonia: Ferronickel	29,531	37,352	36,285	32,278	34,400
Norway: Metal	44,565	52,547	54,886	57,812	58,730
Poland: Unspecified ⁵	(⁶)	(⁶)	(⁶)	(⁶)	—
South Africa, Republic of: Metal	29,248	29,217	27,900	28,133	26,863
Taiwan: Metal	<u>8,165</u>	<u>10,435</u>	<u>10,000</u>	<u>10,400</u>	<u>11,340</u>
U.S.S.R.: ⁷					
Ferronickel	25,000	25,000	25,000	22,700	20,000
Metal	245,800	255,000	255,000	236,000	225,000
Oxide	15,000	15,000	15,000	13,600	12,000
Total	<u>285,800</u>	<u>295,000</u>	<u>295,000</u>	<u>272,300</u>	<u>257,000</u>
United Kingdom: Metal	29,500	27,700	26,100	26,800	29,030

See footnotes at end of table.

TABLE 12—Continued
NICKEL: WORLD PLANT PRODUCTION, BY COUNTRY AND PRODUCT¹

(Metric tons of nickel content)

Country ² and product	1987	1988	1989	1990	1991 ³
United States: Ferronickel	—	—	347	3,701	⁷ 7,065
Yugoslavia:					
Ferronickel ⁴	2,500	5,300	⁵ 5,100	³ 3,600	2,500
Metal	—	—	956	¹ (⁶)	—
Total ⁴	2,500	5,300	⁶ 6,056	³ 3,600	2,500
Zimbabwe: Metal	10,394	11,490	11,633	¹ 11,426	11,400
Grand total	⁸ 857,103	⁹ 929,631	⁹ 933,730	⁸ 883,015	875,636
Of which:					
Chemicals	² 2,330	² 2,973	³ 3,353	² 2,733	3,190
Ferronickel	¹ 175,885	¹ 198,474	² 208,291	¹ 195,930	209,810
Metal	⁵ 583,398	⁶ 606,201	⁶ 601,132	⁵ 577,852	560,636
Oxides	⁹ 95,490	¹ 121,983	¹ 120,954	¹ 106,500	102,000

¹Estimated. ²Revised.

³Table includes data available through May 29, 1992.

⁴In addition to the countries listed, North Korea is believed to have produced metallic nickel and/or ferronickel, but information is inadequate to make reliable estimates of output levels. Several countries produce nickel-containing matte, but output of nickel in such materials has been excluded from this table in order to avoid double counting. Countries producing matte include the following, with output indicated in metric tons of contained nickel: Australia: 1987—47,834; 1988—45,000 (estimated); 1989—45,000 (estimated); 1990—45,000 (estimated); and 1991—45,000 (estimated); Botswana: 1987—16,528; 1988—22,539; 1989—18,552 (revised); 1990—17,880 (revised); and 1991—17,300 (estimated); Canada: 1987—56,558; 1988—57,703; 1989—44,320; 1990—43,300 (estimated); and 1991—40,000 (estimated); Indonesia: 1987—26,508; 1988—28,864; 1989—29,030; 1990—24,949 (revised); and 1991—34,412; and New Caledonia: 1987—8,283; 1988—10,470; 1989—10,650; 1990—9,683; 1991—8,000 (estimated).

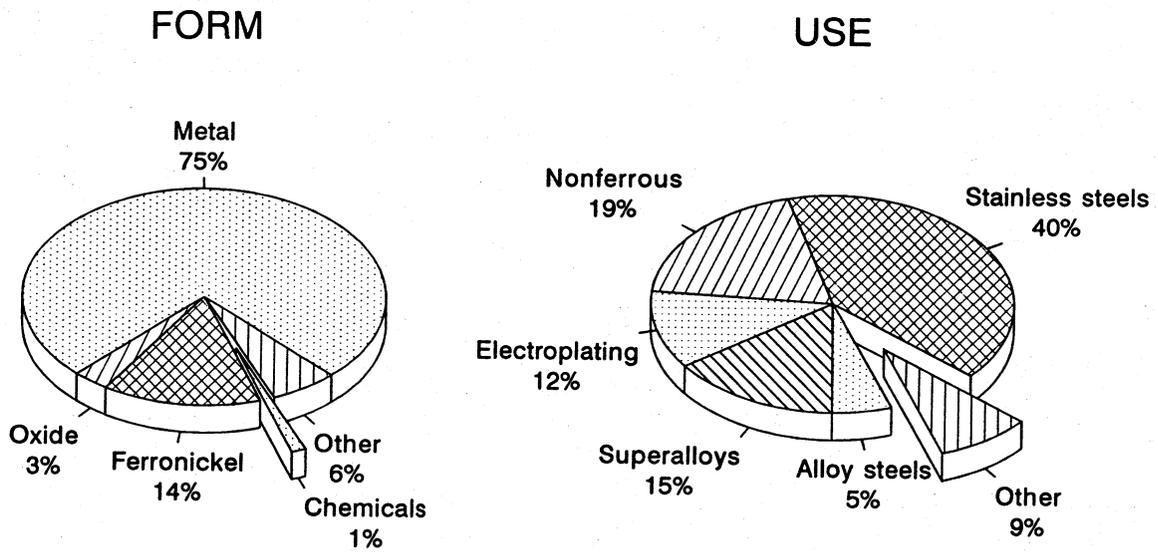
⁵Brazil is believed to also produce nickel oxide, but information is not available on which to base estimates.

⁶Source of data: International Nickel Study Group. World Nickel Statistics, V. 1, No. 1, Dec. 1991, Special Issue, p. 7. Cuba also produces nickel sulfide but, because it is used as feed material elsewhere, it is not included to avoid double counting. Output of processed sulfide was as follows, in metric tons: 1987—16,600; 1988—18,314; 1989—18,475; 1990—16,400 (estimated); and 1991—15,000 (estimated).

⁷Reported figure.

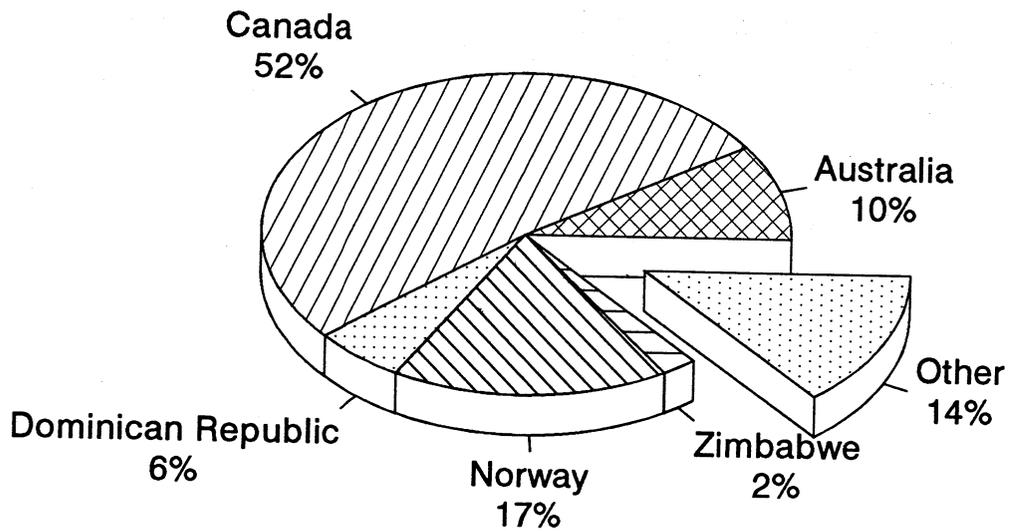
⁸Revised to zero.

FIGURE 1
U.S. PRIMARY NICKEL CONSUMPTION IN 1991, BY FORM AND USE



98,631 METRIC TONS

FIGURE 2
MAJOR SOURCES OF U.S. PRIMARY NICKEL IMPORTS, BY COUNTRY



138,659 METRIC TONS

NITROGEN

By Raymond L. Cantrell

Mr. Cantrell joined the U.S. Bureau of Mines in the capacity of physical scientist, nitrogen commodity specialist, in June 1988. He was previously affiliated with W. R. Grace & Co., Hasbro Industries, and Columbia Nitrogen Corp. Domestic survey data were prepared by Tonya Hardin, statistical assistant; and international data tables were prepared by staff, international data.

War in the Persian Gulf and sweeping political reforms in the U.S.S.R. and Eastern bloc countries commanded global attention in 1991. The Persian Gulf Crisis and Eastern European reforms were not without sacrifice to agriculture, however. Global ammonia production declined by an unprecedented 4.3 million short tons N (4%) to a level of 103.3 million tons.

Strategic supplies of ammonia and urea normally traded from out of the Persian Gulf were cut off altogether or severely curtailed during the Gulf Crisis, and there were severe cutbacks in fertilizer production in Eastern Europe that created food shortages owing to foreign exchange problems.

In the United States, agriculture continued to gain momentum, and ammonia plants ran at near capacity in meeting demand. Global grain stocks declined to the lowest levels since the mid-1970's, which portended a continued strengthening in U.S. agriculture.

The Secretary of Agriculture lowered acreage set-asides for most feed and food grains to 5%, encouraging farmers to bring another 6 to 8 million acres of fallow land back into cultivation during fertilizer year 1991-92. Nitrogen fertilizer consumption was expected to increase 2% to 3% as a result.

Elemental nitrogen gas and liquid (N_2), together with synthetic anhydrous ammonia (NH_3)—a derivative of atmospheric nitrogen and fossil fuels—form the base for an enormous global agricultural and industrial sector. Elemental nitrogen is used extensively by the electronics, metals, food, and

aerospace industries because of its unique inert and cryogenic properties. Nitrogen contained in anhydrous ammonia and its downstream fertilizer derivatives provides more than 50% of the world's essential plant nutrient demand. In the industrial sector, anhydrous ammonia derivatives are important for the production of synthetic fibers, resins and polymers, explosives, animal feeds, and an enormous array of inorganic and organic compounds. (See table 1.)

DOMESTIC DATA COVERAGE

Industry statistics for anhydrous ammonia and derivative products were developed by the Bureau of the Census, U.S. Department of Commerce. Preliminary monthly data were published under product codes 28731, 28732, and 28742 in Current Industrial Reports (CIR), Fertilizer Materials, M28B. In 1991, Census adopted a quarterly format and replaced monthly series M28B with the quarterly series MQ28B, under the same title. Final monthly and quarterly data are subsequently published in a companion annual report MA28B. During 1991, the Bureau of the Census surveyed approximately 250 known producers of inorganic fertilizer materials. Statistics covering industrial gases were reported in the Bureau of the Census CIR publications M28C, M28QC, and MA28C, Industrial Gases.

BACKGROUND

Nitrogen chemical matter developed as part of our solar system about 5 billion

years ago, according to astrophysics. About 4 billion years ago, volcanic activity was believed to have belched gases from the bowels of primordial Earth, forming the nucleus for the nitrogen-rich atmosphere as we know it today. Nitrogen was discovered independently in 1772 by the Swedish druggist, Carl Scheele, and the Scotch botanist, Daniel Rutherford.¹

Nitrogen is an absolute requirement for all life forms on Earth. The gas cycles between its inert diatomic form (N_2) in the atmosphere and chemically fixed forms on Earth, weaving an intricate balance with the carbon cycle that is driven by the photosynthesis processes of living plants. Plants absorb carbon dioxide from the atmosphere, synthesize carbohydrates and essential amino acids and proteins (nitrogen forms), and emit oxygen, all prerequisite to life. The microorganisms of the rhizosphere topsoil supply available mineral nitrogen to nonleguminous plants and biological nitrogen to leguminous (nitrogen fixing) plants for human and animal nutrition.

Planet Earth is enveloped by an atmosphere dominated by nitrogen (N_2), oxygen (O_2), and water vapor (H_2O), above which lies a delicately thin layer of protective ozone (O_3) that screens harmful ultraviolet radiation. Trace gases in the atmosphere such as carbon dioxide (CO_2) absorb much more radiant energy than they release, providing the additional warmth necessary for our habitation of the planet.

The air we breathe consists of about 78% N_2 and about 21% O_2 by volume; argon makes up most of the remainder.

Trace amounts of helium, hydrogen, krypton, neon, and xenon are natural atmospheric sources, together with the greenhouse gases—global warming gases—carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). Fossil fuel combustion has been responsible for a significant buildup in atmospheric CO₂ during the 20th century.

At the turn of the 20th century, natural sources of nitrogen chemical materials supplied virtually all of the nutrient requirements for agricultural crop production. Mineralized organic soil nitrogen, domestic animal manures and byproducts, guano, seed meals, and coke oven ammonia predominated. The mineralized occurrences of sodium nitrate found in the Atacama Desert of northern Chile also provided strategic supplies of agricultural nitrogen to the global community.

In the late-1800's, agronomists warned that a global food crisis would materialize unless supplemental nitrogen forms could be found to increase crop production for the exploding world population. Four major industrial nitrogen fixation technologies evolved between 1900 and 1920: (1) the electric arc process, developed by Birkeland and Eyde in Norway, produced nitric oxide (NO) from atmospheric nitrogen and oxygen that was used to produce nitric acid (HNO₃); (2) the cyanamide process, discovered by Frank and Caro in Germany, synthesized calcium cyanamide (CaCN₂) from calcium carbide (CaC₂) and N₂; (3) the cyanide process, developed by Bucher of Brown University in Rhode Island, produced sodium cyanide (NaCN) from N₂ and sodium carbonate (Na₂CO₃) as an intermediate to ammonia production; and, (4) the ammonia process, developed by Haber and Bosch in Germany, reacted N₂ and hydrogen (H₂) under high temperatures and pressures in the presence of a catalyst to form ammonia (NH₃).

The Haber-Bosch process overshadowed all other industrial methods for producing nitrogen chemical materials and fostered today's mammoth ammonia-based nitrogen fertilizer and industrial sectors. This process was ideally suited

for the large-scale commercial production of ammonia (82.2% N) because of the enormous natural resources of essential chemical feedstock elements: nitrogen from the atmosphere, and hydrogen, derived from coal, petroleum, natural gas, and water.

Definitions, Grades, and Specifications²

At ordinary ambient temperature and pressure, anhydrous ammonia is a colorless gas with a very sharp, characteristic odor. Ammonia condenses to a liquid at minus 28° F. Anhydrous ammonia is not a poison and has no cumulative toxic effects on the human body. It, however, is corrosive and may cause lung, throat, mouth, nose, and eye irritation. When liquid anhydrous ammonia comes into direct contact with the skin, a severe burn may result. Anhydrous ammonia is not combustible except when its concentration in the air falls between 16% to 25% at temperatures in excess of 1,560° F.

Ammonia vapor becomes "life threatening" only when exposure levels reach 2,500 to 6,500 part per million (ppm) for up to 30 minutes or "rapidly fatal" if exposure levels reach 5,000- to 10,000-ppm concentrations for up to 30 minutes. Goggles, respirators, gloves, other protective body gear, and plenty of water—in cases of personal exposure or spills—should be readily available when working with ammonia. Steel is the only acceptable metal allowed in the process of transfer, storage, and transport of anhydrous ammonia.

Technology

Elemental nitrogen is mined from the air by cryogenic separation and membrane technologies. In a typical air separation plant, liquefied air is separated into its individual components by fractional distillation. The resources of nitrogen in the air are virtually unlimited and renewable because of the continuous nitrogen cycle between fixed forms on Earth and atmospheric nitrogen.

Mining.—Mineralized occurrences of sodium nitrate (NaNO₃) and potassium nitrate (KNO₃) are mined in significant quantities in the Atacama Desert of northern Chile. The extremely arid nature of this region, with its paucity of soil microorganisms, creates an ideal environment for preserving the nitrate deposits that formed in Miocene times. The nitrate content of the deposits range from about 6.5% to 50%, with an estimated reserve base of about 2.5 billion tons.

Product grades of sodium nitrate and sodium nitrate-potassium nitrate mixtures are obtained through selective precipitation and filtering, followed by granulation. In 1991, Sociedad Quimica y Minera de Chile S.A. (SQM) produced more than 1 million tons of granular sodium nitrate and mixed potassium products for fertilizer and industrial use.³

SQM's principal product line, in order of importance, included sodium nitrate (16% N) and homogeneous chemical mixtures of sodium nitrate and potassium nitrate containing 15% N and 14% potash (K₂O). Sodium nitrate was also blended with potash to produce a mixed fertilizer containing 13% N and 44% K₂O.

Processing.—Anhydrous ammonia is typically produced through a sequence of catalytically driven reactions involving the steam reforming of natural gas in the presence of air to produce hydrogen and nitrogen in the proper ratio to effect ammonia synthesis. The latest state-of-the-art plants operate at less than 25 million British thermal units (Btu) per ton, resulting in an energy efficiency of more than 70%.

Modern ammonia plants employ efficient centrifugal compressors for air and synthesis gas compression. Temperatures and pressures fluctuate throughout an ammonia plant depending on the process, but typically vary between 600° F to 1,800° F, and 500 to 3,000 pounds per square inch gauge, respectively. A nickel catalyst is used in the reformer and associated front-end sections of the plant, while an iron-promoted catalyst is used for ammonia synthesis.

Urea is formed when ammonia is reacted with byproduct carbon dioxide (CO₂) generated during ammonia synthesis. The materials are reacted under high pressure in a two-step reaction at about 400° F to first form ammonium carbamate, which then decomposes to urea (NH₂CONH₂).

Nitric acid is formed when ammonia is passed over a platinum-rhodium catalyst at about 1,700° F and 120 pounds per square inch gauge. As ammonia passes over the catalyst gauze, it reacts with oxygen to form nitric oxide (NO), which is converted to nitric acid by mixing with water in a countercurrent absorption tower.

Ammonium nitrate, in turn, is formed by the simple acid-based reaction between ammonia and nitric acid, and urea and ammonium nitrate may be blended to produce the popular urea-ammonium nitrate (UAN) solutions containing 28% to 32% N.

Economic Factors

The data of table 2 reflect long-term price trends for U.S. ammonia and natural gas over a period of 22 years (1970-91). The ratio of ammonia prices to natural gas feedstock prices provides a measure of ammonia's relative price sensitivity to changing feedstock costs. This relationship, however, does not give an accurate account of the impact of market forces and improvements in production efficiency on indicative profitability in the U.S. ammonia market.

Between 1970 and the early 1980's, natural gas prices rose dramatically, and ammonia production costs became much more sensitive to feedstock costs. Feedstock costs as a percentage of total production costs rose precipitously, from 45% in 1970 to 75% by 1982. Natural gas prices have declined since 1985, and feedstock costs in 1991 represented about 65% of total ammonia production costs.

The U.S. ammonia industry experienced record profitability during 1974-75 because of a tight global supply-demand situation, in spite of the rising dependency on feedstock costs; a similar situation developed during 1979-81.

Conversely, the U.S. ammonia industry suffered substantial losses in 1986-87 owing to a sustained period of oversupply in the world fertilizer and grain markets.

A dramatic recovery in the U.S. agricultural sector since 1987, accompanied by favorable energy prices, has led to a return to respectable profitability in the domestic converted nitrogen industry.

On April 3, 1990, the New York Mercantile Association (NYMEX) established natural gas futures trading in the United States. Natural gas futures trading was designed to allow suppliers, producers, and end users to shift or hedge price risks. NYMEX believed that natural gas futures contracts would provide the same liquidity, unambiguous price reference, and hedge against risk characterized by its successful petroleum contract system. Futures prices reflected price stability in the U.S. natural gas market for the coming year. (See table 2.)

ANNUAL REVIEW

Legislation and Government Programs

The Food, Agriculture, Conservation, and Trade Act of 1990, Public Law 101-624, signed on November 28, 1990,⁴ created the "triple base flexibility" initiative that gave farmers more freedom to make planting decisions and extended many of the highly successful program initiatives of the 1985 bill. Under the provisions of the 1990 "farm bill," 33 million acres was available to be "flexed" to other crops in 1991, but only about 7.5 million acres actually moved out of the original program crops.

Under triple base, farmers lost Government subsidizes on 15% of their base acreage but gained the flexibility to plant virtually any crop except fruits and vegetables on this land and still receive Government price support loans. The triple base initiative provided the impetus for a \$13 billion reduction in Government "entitlement" farm program spending over a 5-year period as prescribed by the Omnibus Budget Reconciliation Act of

1990 (Public Law 101-508), signed on November 5, 1990.⁵

Total Conservation Reserve Program (CRP) acreage was required to increase from a level of 34 million acres in 1990 to between 40 to 45 million acres by 1995. Following the 10th CRP signup, March 4-15, 1991, total CRP acreage was increased 475,000 acres to a total of 34.4 million acres. Another 1.1 million acres was expected to be accepted following the 11th CRP signup, July 8-19, 1991, raising the CRP participation to 35.5 million acres.

Bids for the 12th CRP signup were to be accepted by county offices of the U.S. Department of Agriculture (USDA) Agricultural Stabilization and Conservation Service, June 15-26, 1992. CRP acreage must be withheld from cultivation for a period of 10 years.

The Commodities Futures Trading Commission (CFTC) approved diammonium phosphate (DAP) futures trading on the Chicago Board of Trade (CBOT) on July 25, 1991. Trading was to commence on October 18, 1991. On October 29, 1991, the CFTC also approved ammonia futures trading on CBOT that was scheduled to commence in 1992.

The historic Clean Air Act of 1990 (Public Law 101-549)⁶ will have monumental economic, health, and trade impacts on both the United States and the world. The massive bill contained 11 titles that targeted 3 principal forms of pollution: acid rain, smog, and toxic air pollutants.

The National Energy Strategy report was issued by the U.S. Department of Energy (DOE) in early 1991 to provide guidance in implementing the new clean air bill, pursuant to the President's directive of mid-1989.⁷ In total, about 30 million tons per year of hazardous chemicals and noxious pollutants was to be removed from the air.

One of the major impacts of the new clean air legislation will be the emphasis placed on clean burning alternative fuels and the use of oxygenated fuels as air pollution control strategies. This new Government policy will have broad implications for both the United States

and the international motor fuels market. The principal fuel oxygenates are methyl tertiary butyl ether (MTBE); ethanol, a derivative of corn; ethyl tertiary butyl ether (ETBE); and tertiary amyl methyl ether (TAME).

The Environmental Protection Agency (EPA) Oxygenated Fuel Program will become effective November 1, 1992, requiring gasoline marketers to supply oxygenated fuels for at least 4 months out of the year having a minimum average oxygen content of 2.7% by weight in the 39 cities that do not meet Federal air quality standards for carbon monoxide (CO). If an inadequate domestic supply of, or distribution capacity for, oxygenated fuels can be demonstrated, EPA may delay implementation for up to two 1-year periods.

EPA's Reformulated Fuel Program will commence on January 1, 1995, wherein the nine worst U.S. ozone nonattainment areas (Los Angeles, New York, Greater Connecticut, Baltimore, Philadelphia, Chicago, Milwaukee, Houston, and San Diego) will be required to sell gasoline with a minimum 2.0% by weight oxygen, 1% maximum by volume benzene, 25% aromatics maximum by volume, and no heavy metals (e.g., lead, manganese).

Information Resources Inc., a Washington, DC, consulting firm, estimates that in 1992, approximately 1.1 billion gallons of ethanol (419 million bushel corn equivalent) will be required to help meet the projected U.S. oxygenated fuel demand created by the Clean Air Act, and up to 2.4 billion gallons (894 million bushel corn equivalent) by the year 2000.⁸

Acid rain is caused primarily by sulfur dioxide (SO₂) and nitrogen oxide (NO_x) emissions from coal-fired electrical powerplants. Under title IV, SO₂ emissions were slated to decline 10 million tons from 1980 levels by the year 2000, and NO_x emissions were to be cut by 2 million tons.

Under title III, a list of 190 hazardous chemicals and materials was established for regulation with the requirement that maximum achievable control technology (MACT) be applied to industries emitting major sources of air pollutants. Several

important industrial nitrogen-containing compounds were on the list, including acrylonitrile, aniline, caprolactam, ethyl carbamate (urethane), hydrazine, coke oven byproducts, and cyanides.

EPA released the preliminary results of its 1989 Toxics Release Inventory (TRI), which indicated that 22,650 industrial facilities released about 3 million tons of toxic chemicals into the Nation's environment. The report disclosed that between 1987 and 1989, TRI chemicals decreased by a favorable 18%.

In 1989, a total of approximately 200,000 tons of ammonia was released into the environment: 61% to the air; water, 6%; injection into underground wells, 17%; municipal waste treatment plants, 14%; and disposal in landfills, 2%. Between 1987 and 1989, ammonia losses to the atmosphere declined by a favorable 18%, and discharges into rivers, lakes, streams, and other bodies of water declined 25%. Ammonia processed through municipal waste treatment plants rose 14%, and underground injection disposal methods increased 17%.

Issues

The large Saskferco ammonia and urea project under construction at Belle Plaine, Saskatchewan, continued to be challenged by the U.S. Ad Hoc Committee of Domestic Nitrogen Producers and the Canadian Council of Nitrogen Producers. The International Trade Commission (ITC), U.S. Department of Commerce, Import Administration (IA), and the U.S. Trade Representative were lobbied by the groups that cited potential injury to other North American nitrogen producers and unfair subsidization of the project, a joint venture between Cargill Fertilizer of Minneapolis, MN, the Crown Corp. of Saskatchewan, and Citibank Canada. Saskferco was scheduled to be on-stream in the fall of 1992.

EPA's Phase II Drinking Water Well Survey released in late-1991 gave new merit to industry calls for site-specificity in solving water quality problems. The multiyear study concluded that nitrate occurrence in U.S. waters is a limited,

site-specific problem and cannot be generally predicted by a simple set of factors. EPA concluded that a variety of environmental conditions and human activities combine to affect the occurrence of pesticides and nitrate in drinking water wells and that no one single factor can explain their presence.

The Fertilizer Institute (TFI), Washington, DC, met with EPA to discuss the nitrate in drinking water issue. TFI pointed out that EPA's study had refuted the commonly held theory that a national drinking water quality problem exists and that a simple reduction in nitrogen fertilizer use would solve the problem. TFI also reported that the few documented cases of methemoglobinemia ("Blue Baby Syndrome") on record involved nitrate levels at several multiples of EPA's 10 ppm limit.

Production

In 1991, the U.S. ammonia industry operated at 96% of rated capacity, indicative of the relatively tight supply-demand conditions. Thirty-four firms in 24 States produced 17.0 million short tons of anhydrous ammonia (82.2% N) compared with 16.8 million tons in 1990. Louisiana, Oklahoma, and Texas, in order of importance, provided about 60% of total U.S. production; the Midwest, South, and Southeast, 30%; and the Western States and Alaska, 10%.

U.S. anhydrous ammonia production was bolstered by a relatively tight supply-demand situation in the domestic and global fertilizer and grain markets and a continued reduction in the trade deficit precipitated by the Persian Gulf crisis and Eastern bloc restructuring. Natural gas feedstock was reasonably priced. The Fertilizer Institute Production Cost Survey for 1991 indicated that overall ammonia production costs declined about 2.5% relative to those of the prior year.

About 90% of U.S. ammonia production was for fertilizer products, and about 10% went into industrial products. Major downstream ammonia fertilizer derivatives included urea (46% N), diammonium phosphate (18% N), ammonium nitrate (35% N), and

ammonium sulfate (21% N). Important industrial chemical derivatives were urea, ammonium nitrate, nitric acid (22% N), acrylonitrile (26% N), and caprolactam (12% N). (See tables 3 and 4.)

In January, the W. R. Grace Agricultural Chemicals Group in Memphis, TN, sold its ammonia interests at Point Lisas, Trinidad, to Norsk Hydro a.s. of Norway. Included in the sale were Grace's wholly owned Federation Chemicals Ltd. ammonia plant (255,000 annual tons) and a 49% share in Trinidad Nitrogen Co. Ltd., a joint venture with the Government of Trinidad and Tobago in two ammonia plants (Tringen I & II), having a combined annual capacity of 920,000 tons.

Grace also transferred ownership of its U.S.-based marketing operations and shipping interests that were linked to the output of the Trinidad facilities. Hydro Agri Ammonia, Inc. (HAAI), a U.S. affiliate of Norsk Hydro, was established in Tampa, FL, for this purpose. HAAI was staffed by key personnel from the former Grace marketing team in Memphis, TN.

In November, Norsk became a joint-venture partner in Farmland Industries' Green Bay, FL, phosphate operation. The Farmland Hydro Limited Partnership group began operating from headquarters in Bartow, FL, on November 16. The Green Bay facility had a DAP-monoammonium phosphate (MAP) production capability of 1 million annual tons.

In 1991, Chevron followed through on previous plans to exit the U.S. nitrogen and phosphate fertilizer sectors. The large 530,000-ton-per-year ammonia plant at Pascagoula, MS, was dismantled and rumored to be destined for Pakistan, while Monsanto picked up Chevron's 50% interest in the 490,000-ton-per-year joint-venture ammonia plant at Luling, LA.

Farmland Industries, Inc., purchased Chevron's Finley, WA, nitrogen solutions plant in January and planned to move the unit to its primary nitrogen production complex at Enid, OK.

In November, Chevron signed an agreement in principal to sell the Vernal,

UT, phosphate rock and Rock Springs, WY, DAP operations to a proposed partnership between Farmland Industries and J. R. Simplot, subject to Federal Trade Commission (FTC) approval. Annual DAP production capability at Rock Springs was 450,000 tons.

In December, Unocal purchased Chevron's 140,000-ton-per-year ammonia plant at Finley, WA. Unocal planned to permanently close the ammonia plant and use the facility for storage and distribution. Unocal was to toll ammonia from Chevron's 20,000-ton-per-year El Segundo, CA, plant. Chevron planned to continue operation of an 80,000-ton-per-year ammonia plant at St. Helens, OR, until a buyer could be found.

Cargill Fertilizer of Minneapolis, MN, was building a C\$435 million nitrogen fertilizer complex—the Saskferco project—in Belle Plaine, Saskatchewan, through a corporation formed between its Canadian subsidiary, Cargill Ltd., the Crown Investments Corp. of the Province of Saskatchewan, and Citibank Canada. The plant was scheduled for completion in the fall of 1992 and was designed to produce 560,000 tons per year of ammonia and 750,000 tons per year of granular urea.⁹

CF Industries is one of North America's largest interregional cooperatives, owned by and serving 12 regional cooperatives. Through its members, the company's nitrogen, phosphate, and potash fertilizer products reach more than 1 million farmers and ranchers in 46 States and 2 Canadian provinces.

In June, the Board of Directors authorized an expenditure of \$87 million to reconfigure product mix at CF's Donaldsonville Nitrogen Complex. When completed in the 1994 fertilizer year, this project will increase production capacity for granular urea and UAN solutions. The additional capacity will allow CF Industries to meet the projected needs of its members during the 1990's.¹⁰

CF's Donaldsonville ammonia plants were capable of operating at 2 million tons per year, 120% of design capacity, because of recent revamp and retrofit initiatives that included a significant

reduction in NO_x emissions. The planned expansions will lead to further improvements in the cooperative's competitive economics. (See table 5.)

In November, Koch Industries, Inc., signed a letter of intent to purchase the IMC Fertilizer Group, Inc. (IMCF) large ammonia complex at Sterlington, LA. The Sterlington complex consists of two ammonia trains having a total capacity of 1.1 million tons per year. The acquisition would provide a good fit for Koch Industries, owner of the Gulf Central Pipeline that serves the Sterlington plant. An ammonia supply contract for IMCF's New Wales, FL, DAP-MAP complex was also to be negotiated.

Mississippi Chemical Corp. (MCC) was constructing a new 200,000-ton-per-year nitric acid plant at Yazoo City, MS, scheduled on-stream in late 1992. MCC produces ammonia, nitric acid, ammonium nitrate, urea, and UAN solutions at Yazoo City, MS.

MCC could not find a buyer for its repossessed DAP plant at Pascagoula, MS, and planned to start up late in the year based on imported Moroccan phosphate rock. Atlantic Fertilizer and Chemical Corp. contracted to market the DAP output rated at 700,000 tons per year. The firm also has a 50% interest in Triad Chemical Co., a major ammonia and urea production complex at Donaldsonville, LA.

Nitrogen Products, Inc. brought a revamped 210,000-ton-per-year ammonia plant on-stream at Helena, AR, in January. The Dutch-owned bank NMB contracted with Royster Co. to operate the new venture. Late in the year, Royster was reported to withdraw as the operator owing to its own bankruptcy proceedings. The former Big River ammonia plant at Helena had been purchased by an investment consortium in bankruptcy proceedings during 1989 and renamed Five Rivers. The plant was subsequently closed in mid-1990 owing to a lack of reliable power sources and equipment failures. Ownership was transferred to the original lending institution, NMB.

Diamond Shamrock acquired the Center Plains ammonia facility at Dumas, TX, in bankruptcy proceedings through a repurchase agreement in 1990 and reactivated one of the two 80,000-ton-per-year plants on-site in early 1991.

In October 1991, Agricultural Minerals Corp. (AMC) announced that it would go public on the New York Stock Exchange as Agricultural Minerals Co. LP. AMC assumed control of Agrico's former nitrogen fertilizer production facilities at Verdigris, OK, and Blytheville, AR, effective March 1, 1990, and established headquarters in Tulsa, OK. Ammonia, urea, and UAN solutions are the primary products produced by AMC, along with the highly efficient slow-release Super N fertilizers containing dicyandiamide. AMC was among the top five U.S. nitrogen fertilizer producers.

Terra International, Inc. announced a 75,000-ton-per-year ammonia expansion at Port Neal, IA, scheduled for completion in late 1992. Emissions were also to be reduced 30%.

Coastal Chem, Inc. planned a 175,000-ton-per-year ammonia expansion by late 1992 at Cheyenne, WY, based on the reconstruction of a plant to be moved from Arcadian's Augusta, GA, complex. Coastal was constructing a 130,000-ton-per-year nitric acid plant at Elko, WY, that would be used to produce ammonium nitrate-based explosives.

BP Chemicals announced a \$17 million 90,000-ton-per-year nitric acid replacement-expansion at Lima, OH, that was scheduled on-stream in late 1992.

Consumption and Uses

U.S. apparent domestic consumption of ammonia was 19.7 million product tons in 1991, similar to that of the prior year. Fertilizer materials accounted for about 80% of domestic ammonia conversion disappearance, and about 20% went into industrial applications.

Urea and ammonium nitrate, in solid and liquid form, found extensive use in both the fertilizer and industrial sectors. UAN solution fertilizers that contain 28% to 32% N were growing in popularity

because of their safe handling and storage characteristics and ease of application.

In the industrial sector, urea was used in the production of synthetic fibers, resins, and polymers and as a protein supplement in ruminant animal feeds. Ammonium nitrate fuel oil explosives (ANFO) dominated the industrial explosives sector. Nitric acid was used in chemical synthesis and in metal treatment. Acrylonitrile and caprolactam found respective use in the production of acrylic and nylon fibers, resins, and plastics. (See table 6.)

Other uses for ammonia and ammonia-base compounds were for specialty horticultural and lawn and garden fertilizers, home and industrial cleaners, fuel ethanol derived from corn and other biomass species, and as a propellant in vehicular air bags. Ammonia and urea were also becoming popular low-cost agents that significantly reduced NO_x atmospheric emissions when injected into combustion gas streams.¹¹

In 1991, ammonia and ammonia derivatives accounted for 55% of the 20.3 million ton primary fertilizer nutrient market in the United States. The ratio of nitrogen nutrient consumption to phosphate and potash fertilizer nutrient consumption was 2.7:1 and 2.2:1, respectively.

U.S. nitrogen fertilizer consumption reached 11.2 million tons N in 1991 compared with 11.1 million tons N in 1990. Single-nutrient compounds led by direct application ammonia, UAN solutions, urea, and ammonium nitrate, in order of importance, provided 80% of the total. Direct application ammonia consumption increased 9%. (See table 7.)

The six States that comprise the Midwest Corn Belt—Illinois, Indiana, Iowa, Missouri, Nebraska, Ohio—together with Minnesota, consumed 4.6 million tons N, 42% of the U.S. total. Texas, Kansas, California, and Oklahoma, in order of importance, accounted for 2.4 million tons N, 21% of the total.

U.S. net cash farm income in 1991 was expected to approximate \$56 billion, about 7% below the record \$60 billion

established in 1990. Planted crop acreage approximated 338 million acres, and another 63 million acres was idled by crop programs and the CRP. Carryout inventories of major feed and food grains were at the lowest levels in years.

Stocks

U.S. stocks of major nitrogen compounds increased about 10% at the producer level and ended the year at 1.8 million tons N. This was not surprising in light of the inventory drawdowns experienced in 1990. (See table 8.)

Transportation

Ammonia was transported by refrigerated barge, rail, pipeline, and truck. In late 1990, the Research and Special Programs Administration (RSPA) of the U.S. Department of Transportation (DOT) classified anhydrous ammonia as a nonflammable gas linked to a required "inhalation hazard" label. RSPA officially classified anhydrous ammonia a Division 2.2 nonflammable, nonpoisonous compressed gas for domestic shipments. The inhalation hazard label was to become effective October 1, 1991.¹²

International shipments, however, were classified as a Division 2.3 "poison gas" consistent with United Nation regulations. International shippers were required to comply under the new regulations on January 1, 1991. Because of the documented inhalation hazards of anhydrous ammonia when released in large quantities, RSPA was also requiring the words "INHALATION HAZARD" on packages and shipping papers, in addition to other current hazard communications information.

The Interstate Commerce Commission (ICC) replaced the Federal Energy Regulatory Commission (FERC) as the Federal agency responsible for ammonia pipeline regulation in late-1990. FERC had been responsible for ammonia pipeline regulation since 1977, when ICC transferred power of control under the Department of Energy act. Actions on complaints that had been previously filed with FERC against ammonia pipelines for

alleged excessive rate charges were delayed because of the transfer after the U.S. Court of Appeals ruled in favor of ICC control.

Koch Industries operated the Gulf Central Pipeline built in 1969 that extended about 1,900 miles from the Gulf of Mexico into the Midwest, as far north as Iowa. Koch Nitrogen, a subsidiary, purchased four Midwest ammonia terminals from ConAgra Fertilizer in 1991 having a combined capacity of 150,000 tons. The firm also signed a letter of intent to purchase IMCF's large ammonia complex at Sterlington, LA, along the path of the pipeline.

Mapco Ammonia Pipeline Inc. operated Mapco Ammonia Pipeline and its sister company, Mid-America Pipeline, along a 1,098-mile corridor that extended in a northeasterly direction from Borger, TX, in northern Texas, to Mankato, MN, in southern Minnesota. Mapco built the first leg of the pipeline in 1968-69 and, by 1978, had added six extensions. About 500,000 tons of ammonia storage capacity was located along the pipeline.

Mapco Ammonia Pipeline neither produced nor marketed ammonia independently, but transported ammonia on behalf of five shippers. Competition from the rail and truck transportation sectors was minimized because areas served by Mapco Ammonia Pipeline did not have river access. Mid-America Pipeline had more than 400 shippers and competed with the other transportation sectors.¹³

Seminole Fertilizer Corp. and the Royster Co. operated a joint-venture ammonia pipeline that serves ammonium phosphate producers in Florida. Royster was in chapter 11 proceedings, and several companies, including Norsk Hydro and CF Industries, were bidding on the venture. IMCF also operated an ammonia pipeline in Florida for the same purpose.

Markets and Prices

The dramatic rise in nitrogen fertilizer prices precipitated following Iraq's invasion of Kuwait in early August 1990 continued into the first quarter of 1991 on

the heels of Operation Desert Storm. Anhydrous ammonia prices, f.o.b. barge, New Orleans, held steady at \$115 to \$117 per ton during January and February, and then gradually declined to slightly below \$100 by the end of March when supplies were again available from the Persian Gulf. Granular urea prices, f.o.b. New Orleans, remained firm during the first quarter, and ranged between \$151 to \$155 before beginning a gradual decline in the second quarter.

Ammonia and urea prices began to firm up again during the fall season before weakening during November and December. Ammonia and urea prices peaked in October at an average of \$122 per ton and \$138 per ton, respectively, before ending the year at \$111 per ton and \$130 per ton. (See table 9.)

Foreign Trade

U.S.S.R. anhydrous ammonia import tonnage data continued to be withheld from the public domain during 1991, because of a previous ruling by the Bureau of the Census that determined Occidental Petroleum to be the proprietary U.S. agent.

In 1991, the U.S. ammonia trade deficit was estimated at 2.9 million product tons, the same as that in 1990, and 13% favorable to the record 3.4 million ton deficit established in 1989. Ammonia imports were valued at \$391 million and carried an average landed price of \$106 per ton, c.i.f., in comparison to \$100 per ton in 1990.

About 90% of total U.S. ammonia imports was equally divided between Trinidad and Tobago, Canada, and the U.S.S.R., with Mexico providing most of the remainder. The U.S.S.R. shipped a record 1.0 million product tons of ammonia to the United States in 1991 that was valued at \$101 per ton, according to U.S. Bureau of Mines estimates, and this was somewhat surprising in light of the rapid move toward democratization. (See tables 10 and 11.)

The United States experienced a total converted nitrogen trade deficit of 0.6 million tons N in 1991, 0.6 million tons (50%) favorable to the 1.2 million ton

deficit of 1990. A converted nitrogen trade deficit occurs whenever aggregate U.S. nitrogen compound imports exceed exports. U.S. converted nitrogen trade deficits have occurred consecutively since 1981, reaching a record 2.2 million tons N in 1986.

Anhydrous ammonia (2.4-million-ton N deficit) and urea (0.3-million-ton N deficit) were the predominate trade deficit materials. In contrast, DAP generated 1.9 million tons of positive N export trade. Industry sources indicated that U.S. DAP export tonnage could be approximately 700,000 product tons on the high-side because of double counting of vessels at various U.S. ports.

The United States imported 1.8 million product tons of urea from 15 countries in 1991 that was valued at \$209 million (\$117 per ton, c.i.f.). Urea import volume was down 0.3 million tons (14%) compared to 1990 levels, and the landed price declined \$5 per ton (4%). Canada shipped 71% of the total, Mexico, Trinidad and Venezuela, 15% in aggregate, the Netherlands and France (4% total), and Bulgaria, 3%. Germany shipped 4% of the total at a value of \$149 per ton, c.i.f., well above the \$117 per ton average.

ITC urea antidumping duties levied against the U.S.S.R., the Federal Republic of Germany (Eastern states), and Romania, have been effective in preventing the subject countries from landing urea at prices below fair market value. (See tables 12 and 13.)

World Review

Events in Eastern Europe and the Persian Gulf dominated the global nitrogen fertilizer scene in 1991, causing an unprecedented decline in global ammonia production of 4.3 million short tons N (4%). Production declined 1.2 million tons N (4%) in the U.S.S.R. and 1.7 million tons N (26%) in the Eastern bloc countries. Persian Gulf production declined 0.8 million tons (21%). The total loss in ammonia production for these regions amounted to 3.7 million tons N, or 85% of the global decline.

Operation Desert Storm, the United Nations initiative to liberate Kuwait from Iraqi occupation, resulted in severe damage to nitrogen plants in both Kuwait and Iraq during January and February. Information available on the damage and destruction of nitrogen production facilities in the two countries indicated that it would take a minimum of 5 years to bring nitrogen output back to normal.

Iraq and Kuwait, in combination, had represented about 1.5% of total world ammonia capacity and 2.5% of world urea capacity. In 1989, Iraq and Kuwait accounted for about 5% of total world urea and ammonia N trade. This, together with the supply potential of the other Persian Gulf countries, accounts for about 15% of world nitrogen trade in the form of ammonia and urea.

In Eastern Europe, the drive toward democratization was accompanied by sweeping political reforms that placed downward pressure on local economies. Fossil fuel energy essential to ammonia production was in short supply and portended significant shortfalls in nitrogen fertilizers critical to domestic consumption and trade.

Industry Structure.—Approximately 103 million short tons of anhydrous ammonia N was produced in 65 countries during 1991, of which about 10 million tons N (10%) was directly traded. Ammonia was converted into about 39 million tons of urea N in 55 countries, of which about 10 million tons (26%) was traded. Total world nitrogen fertilizer consumption fell about 3% to a level of about 85 million tons N, and trade accounted for about 21 million tons N, or 25% of the total.

Global ammonia was produced in the developed and developing countries that have access to fossil fuel feedstocks, principally, natural gas, naphtha, petroleum refinery offgases and condensates, and coal and coke gases. The supply pattern, in general, followed the world population trend, with Asia and Eastern Europe—including the U.S.S.R.—accounting for more than 60% of the global ammonia supply. The developed regions—North America (United States and Canada), Western

Europe, and Oceania—produced ammonia primarily for domestic use and accounted for about 25% of the world total. The energy-rich countries of the Middle East accounted for about 5% of the world supply and exported significant quantities of ammonia and urea to the global community.

Capacity.—The data in table 14 are rated capacity for ammonia plants as of December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

In 1991, there was a net loss of about 1.5 million annual tons (1%) in global ammonia capacity owing principally to the damage and destruction of plants in Kuwait and Iraq. In Kuwait, 100% of the country's 1.1-million-ton-per-year ammonia industry was expected to be inoperable through 1993 and not completely restored to 1990 levels until after 1996.

Iraq's 1.1 million-ton-per-year ammonia industry was inoperable in 1991, but the new 365,000-ton-per-year plant at Baiji was expected to come on-stream in 1992. One of the two 365,000-ton trains damaged at Khor Al Zubair was expected to be operational by 1994, bringing Iraqi capacity to 730,000 tons per year. Preinvasion capacity levels were not expected to be operational until beyond 1996.

Major world ammonia capacity contracted or under construction and scheduled on-stream during 1991-94, was as follows: China—1.5 million annual tons in Henan, Liaoning, and Sichuan Provinces; India—1.4 million tons at Babrala, Gadepan, and Kakinada; Indonesia—1.4 million tons at Citampek, Gresik, and Palembang; U.S.S.R.—1.1

million tons at Mendeleevsk and, Novgorod, in the Russian Republic; Bangladesh—0.7 million tons at Jamalpur and Chittagong; Belgium—0.7 million tons, Antwerp; Pakistan—0.7 million tons at Iskanderabad, Daudkhel, and Sadiqabad, Punjab; Canada—0.6 million tons, Belle Plaine, Saskatchewan; Saudi Arabia—0.6 million tons, Al Jubail; Egypt—0.5 million tons at Abu Qir and Suez; Iran—0.4 million tons at Mashad, Khorasan; Turkey—0.4 million tons, Gemlik; South Africa—0.3 million tons, Sasolburg; and Argentina and Trinidad and Tobago—0.1 million annual tons each at Huincul, Neuquen, and Point Lisas, respectively. (See table 14.)

Current Research

In January 1991, USDA and DOE signed a "memorandum of understanding" that will coordinate each Department's efforts in the area of biomass research, accelerating the development of ethanol and other alternative fuels and fuel additives from agricultural and forestry products.¹⁴

This agreement promised significant new markets for U.S. farmers and supported the President's National Energy Strategy that focused on a reduction in foreign energy dependency and a cleaner environment. The President's request for renewable energy research and development for fiscal year 1993 is \$250 million, representing more than a 65% increase over funding in fiscal year 1989. The budget request includes \$46 million for ethanol and biomass research in DOE, representing a 265% increase from fiscal year 1989 appropriations.

In September 1991, the President designated the Solar Energy Research Institute at Golden, CO, as the National Renewable Energy Laboratory (NREL). Elevating the status of this facility to a National Laboratory reflects the strong commitment to renewable energy technology research and development (R&D). During 1991, NREL signed a cooperative R&D agreement with a corn-ethanol producer to test a process to convert the cellulose in corn into ethanol. Later in the year, DOE signed a similar

cooperative agreement with a major oil company to explore ethanol production from waste paper.

In April 1992, work will begin on the National Alcohol Fuels User Facility in Golden, CO. This work will include construction of a process development unit for testing new biofuel conversion technology. DOE will develop a cellulose-to-ethanol process development unit at NREL. The unit will evaluate methods for converting wood cellulose into ethanol fuels and serve as the centerpiece for the National Alcohol Fuels User Facility.¹⁵

M. W. Kellogg of Houston, TX, announced two major advances in its ammonia process technology: the Kellogg Reforming Exchanger System (KRES) and the Kellogg Advanced Ammonia Process (KAAP), a joint technology development with British Petroleum.

Kellogg's KRES design was revolutionary in that it completely eliminated the conventional fired primary reformer from the ammonia production process. KRES is environmentally attractive because without a primary reformer, nitrogen oxide emissions are substantially reduced. The system could be easily installed in new or existing plants and would save up to 10% on capital costs.

The KAAP process employs a novel ammonia synthesis catalyst that was claimed to be the first significant breakthrough in catalyst technology since 1927. The proprietary KAAP catalyst is up to 20% more active than conventional iron catalysts. The KAAP system was to be employed in a retrofit project designed to increase production capability by 40% at Ocelot's ammonia plant in Kitimat, British Columbia.

Exxon Research and Engineering Co. of Florham Park, NJ, developed the THERMAL DeNO_x Process that significantly reduced NO_x emissions by injecting ammonia into flue gas streams emanating from stationary combustion sources. THERMAL DeNO_x is a noncatalytic process for NO_x reduction based on the gas phase homogeneous reaction between NO_x in flue gas and ammonia that produces nitrogen and

water. The patented process was offered for license by Exxon Research and Engineering Co.¹⁶

OUTLOOK

Global ammonia operating rates declined to a weak 81% in 1991 owing to a continuation of the downturn in the Eastern European supply-demand situation and supply disruptions precipitated by the Persian Gulf crisis. Per capita nitrogen consumption dropped to a dismal 38 pounds compared with the previous norm of about 42 pounds.

The world ammonia supply-demand outlook anticipated by the U.S. Bureau of Mines suggests that soft market conditions will prevail between 1992 and 1994, principally because of significant new additions to world capacity and a protracted period of economic recovery anticipated in Eastern Europe. There appears to be a favorable probability that the current imbalance between ammonia supply and demand will begin to improve by 1995. A firm global urea supply-demand situation is anticipated between 1992 and 1994, however, because of the current imbalance between ammonia and urea capacities and strong demand in China and other Asian countries.

The U.S. Bureau of Mines ammonia nitrogen demand forecast was developed from World Bank-United Nations Fertilizer Working Group projections¹⁷ taking into consideration world per capita consumption trends and geopolitical factors in Eastern Europe and the Mideast. Steady-state conditions were assumed for weather. World ammonia capacity projections were provided by the International Fertilizer Industry Association Ltd., Paris, France.

In the United States, the outlook for continued strength in the nitrogen fertilizer and grain sectors is anticipated. The ammonia industry is running at near capacity, grain stocks are at the lowest levels in years, U.S. ammonia capacity expansion plans are minimal, and agronomic fundamentals that were improved by the 1985 farm bill should be further perpetuated by the new 1990 farm bill.

The mechanisms of the new CRP, together with regular farm program acreage reductions, should hold U.S. crop acreage at about the current 340 million acres. This, together with the Export Enhancement Initiative, should control crop inventories and provide favorable crop prices for the U.S. farmer. (See table 15.)

The U.S. nitrogen supply-demand outlook will be critically dependent upon: (1) a continuation of reasonably priced natural gas for U.S. ammonia production; (2) new industrial outlets for U.S. agricultural crops, including corn-based ethanol in reformulated motor fuels under the provisions of the Clean Air Act of 1990; (3) new markets for the massive Saskferco ammonia and urea nitrogen complex scheduled on-stream in the fall of 1992 in Saskatchewan, that would minimize the closure of U.S. nitrogen fertilizer capacity; (4) a favorable resolution of the ongoing Uruguay Round of General Agreement on Tariffs and Trade (GATT) negotiations that would liberalize global agricultural trade and provide opportunities for the United States to compete more effectively in world grain trade; (5) favorable U.S. implications for the proposed Free Trade Agreement with Mexico and for the granting of most favored nation (MFN) status to the U.S.S.R. and other Eastern European countries; (6) a smooth transition in democratic reforms in Eastern Europe; and (7) resolution of the MFN status debate with the Republic of China. (See table 16.)

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³Fertilizer Focus. New Way Ahead for SQM. V. 8, No. 4, Middlesex, England, May 1991, pp. 67-70.

⁴U.S. President. Presidential documents, v. 26, No. 48, Dec. 3, 1990. Office of the Federal Register, Washington, DC, 1990, pp. 1926-1928.

⁵_____. Presidential documents, v. 26, No. 45, November 12, 1990. Office of the Federal Register, Washington, DC, 1990, pp. 1764-1766.

⁶_____. Presidential documents, v. 26, No. 46, Nov. 19, 1990. Office of the Federal Register, Washington, DC, 1990, pp. 1824-1826.

⁷U.S. Department of Energy. National Energy Strategy, Powerful Ideas for America. First ed. Washington, DC, Feb. 1991, 267 pp.

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⁹Cargill Fertilizer. Fertilizer Applications. V. 6, No. 1, spring 1991, 7 pp.

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¹³Mapco Ammonia Pipeline, Inc. Green Markets Ammonia Conference, Scottsdale, AZ, Oct. 29, 1990, 8 pp.

¹⁴U.S. Department of Agriculture. USDA, DOE to Collaborate on Alternative Fuels Research and Development. Office of Public Affairs, Mar. 1, 1991.

¹⁵U.S. Department of Energy. National Energy Strategy, One Year Later, Powerful Ideas for America. Washington, DC, Feb. 1992, 66 pp.

¹⁶THERMAL DeNO_x Process, (technical literature) Exxon Research and Engineering Co., Florham Park, NJ 07932.

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TABLE 1
SALIENT AMMONIA STATISTICS¹

(Thousand short tons of contained nitrogen unless otherwise specified)

	1987	1988	1989	1990	1991 ²
United States:					
Production	13,232	13,827	*13,536	*13,806	13,991
Exports	848	642	381	531	639
Imports for consumption	2,357	3,032	3,154	2,947	3,023
Consumption, apparent ²	15,193	16,250	*16,393	*16,279	16,224
Stocks, Dec. 31: Producers ⁷	1,053	1,020	936	879	1,030
Price per ton product, yearend, f.o.b. gulf coast ³	*\$95	*\$99	*\$94	*\$96	\$106
Net import reliance ⁴ as a percent of apparent consumption	13	15	*17	15	14
Natural gas price: Wellhead ⁵	\$1.67	\$1.69	\$1.69	*\$1.71	\$1.59
World:					
Production	*104,849	*109,442	*109,184	*107,561	*103,308
Trade ⁶	9,080	10,210	10,830	*10,920	*10,000

*Estimated. ²Preliminary. ⁷Revised.

¹Synthetic anhydrous ammonia, calendar year data; excludes coke oven byproduct.

²Calculated from production, plus imports minus exports plus and/or minus industry stock changes.

³Green Markets, Fertilizer Market Intelligence Weekly, Pike & Fischer, Inc.

⁴Defined as imports minus exports plus adjustments for industry stock changes.

⁵Monthly Energy Review, U.S. Department of Energy. Average annual cost at wellhead in dollars per thousand cubic feet.

⁶International Fertilizer Industry Association statistics World Anhydrous Ammonia Trade.

TABLE 2
TIME-PRICE RELATIONSHIPS FOR AMMONIA AND NATURAL GAS

(Dollars per ton and dollars per million Btu)

Year	Ammonia		Natural gas		Ammonia-natural gas ratio
	Actual value ¹	Constant 1991 dollars	Actual value ²	Constant 1991 dollars	Actual value ³
1970	34.00	113.00	0.17	0.57	200
1971	34.00	108.00	.18	.57	189
1972	35.00	106.00	.19	.57	184
1973	43.00	122.00	.22	.62	195
1974	93.00	242.00	.30	.78	310
1975	148.00	352.00	.44	1.05	336
1976	107.00	239.00	.58	1.30	184
1977	102.00	213.00	.79	1.65	129
1978	102.00	198.00	.91	1.77	112
1979	107.00	191.00	1.18	2.11	91
1980	130.00	212.00	1.59	2.59	82
1981	146.00	217.00	1.98	2.94	74
1982	141.00	197.00	2.46	3.43	57
1983	139.00	187.00	2.59	3.48	54
1984	152.00	195.00	2.66	3.42	57
1985	140.00	174.00	2.51	3.11	56
1986	102.00	123.00	1.94	2.34	53
1987	98.00	115.00	1.67	1.95	59
1988	105.00	118.00	1.69	1.90	62
1989	105.00	113.00	1.69	1.82	62
1990	103.00	107.00	1.71	1.77	60
1991 ^p	110.00	110.00	1.59	1.59	69

^pPreliminary.

¹Value of shipments, f.o.b. plant, in dollars per ton.

²Value at Wellhead, in dollars per million Btu.

³Ratio of ammonia value to natural gas value.

Sources: Bureau of the Census (ammonia prices); Department of Energy (natural gas prices). The implicit price deflators for 1991 are based on "gross domestic production" and not "gross national product," which was used previously. In addition, the base year has been revised from 1982 to 1987.

TABLE 3
FIXED NITROGEN PRODUCTION IN THE UNITED STATES

(Thousand short tons of contained nitrogen)

	1987	1988	1989	1990	1991 ^p
Anhydrous ammonia, synthetic:¹					
Fertilizer	12,019	12,566	^r 12,270	^r 12,586	12,765
Nonfertilizer	1,213	1,261	1,266	^r 1,220	1,226
Total	<u>13,232</u>	<u>13,827</u>	<u>^r13,536</u>	<u>^r13,806</u>	<u>13,991</u>
Byproduct ammonia, coke plants:²					
Ammonium sulfate ^a	50	60	60	50	45
Ammonia liquor ^a	5	5	6	5	4
Total ^a	<u>55</u>	<u>65</u>	<u>66</u>	<u>55</u>	<u>49</u>
Grand total	<u>13,287</u>	<u>13,892</u>	<u>^r13,602</u>	<u>^r13,861</u>	<u>14,040</u>

^aEstimated. ^pPreliminary. ^rRevised.

¹Current Industrial Reports, MA28B, M28B, and MQ28B Bureau of the Census.

²Quarterly Coal Report, U.S. Department of Energy. Production (1985-91) based on reported coke production trend.

TABLE 4
MAJOR DOWNSTREAM NITROGEN COMPOUNDS PRODUCED IN THE
UNITED STATES¹

(Thousand short tons)

Compound	1987	1988	1989	1990	1991 ^P
Urea:					
Gross weight	7,433	7,914	⁸ 8,004	⁸ 8,120	8,072
Nitrogen content	3,419	3,640	³ 3,682	³ 3,735	3,713
Ammonium phosphates:²					
Gross weight	13,352	15,121	¹⁶ 16,382	¹⁸ 18,358	17,190
Nitrogen content	2,296	2,591	² 2,774	³ 3,080	2,888
Ammonium nitrate:					
Gross weight	6,547	7,504	7,871	⁷ 7,081	7,309
Nitrogen content	2,291	2,626	2,755	² 2,478	2,558
Ammonium sulfate:³					
Gross weight	2,189	2,333	² 2,384	² 2,540	2,230
Nitrogen content	460	490	⁵ 501	⁵ 533	468
Nitric acid, direct use:⁴					
Gross weight	2,069	2,082	2,151	² 2,424	1,768
Nitrogen content	460	463	478	⁵ 539	393
Acrylonitrile:					
Gross weight	1,275	1,288	1,304	1,514	1,324
Nitrogen content	337	340	344	400	350
Caprolactam:					
Gross weight	580	631	656	690	642
Nitrogen content	72	78	81	86	80
Total:					
Gross weight	33,445	36,873	³⁸ 38,752	⁴⁰ 40,727	38,535
Nitrogen content	9,335	10,228	¹⁰ 10,615	¹⁰ 10,851	10,450

^PPreliminary. ^RRevised.

¹Ranked in relative order of importance.

²Diammonium phosphate (DAP), monoammonium phosphate (MAP), and other ammonium phosphates.

³Excludes coke plant ammonium sulfate.

⁴Gross nitric acid production adjusted for use in production of ammonium nitrate.

Sources: Bureau of the Census and International Trade Commission.

TABLE 5
DOMESTIC PRODUCERS OF ANHYDROUS AMMONIA IN 1991

(Thousand short tons per year of ammonia)

Company	Location	Capacity ¹
Freeport-McMoRan (Agrico)	Donaldsonville, LA	500
Agricultural Minerals Corp. ²	Blytheville, AR	400
Do.	Verdigris, OK	1,000
Air Products and Chemicals Inc.	New Orleans, LA ³	290
Do.	Pace Junction, FL	100
Allied Chemical Corp.	Hopewell, VA ³	410
American Cyanamid Co.	Fortier, LA ³	425
Ang Coal Gas	Beulah, ND	24
Arcadian Corp. ⁴	Augusta, GA	545
Do.	Clinton, IA	260
Do.	Geismar, LA	410
Do.	Lake Charles, LA	440
Do.	LaPlatte, NE	190
Do.	Woodstock, TN	340
Borden Chemical Co.	Geismar, LA	400
Carbonaire Co. Inc.	Palmerton, PA	35
CF Industries Inc.	Donaldsonville, LA	1,770
Chevron Chemical Co.	El Segundo, CA	20
Do.	Pascagoula, MS ⁵	—
Do.	St. Helens, OR	80
Do.	Finley, WA	140
Coastal Chem, Inc. ⁶	Cheyenne, WY	170
Cominco American Inc.	Borger, TX ³	400
Diamond Shamrock	Dumas, TX	77
E.I. du Pont de Nemours & Co. Inc.	Beaumont, TX	490
Farmland Industries Inc.	Beatrice, NB ³	250
Do.	Dodge City, KS ³	220
Do.	Enid, OK ³	900
Do.	Fort Dodge, IA	210
Do.	Hastings, NE	7—
Do.	Lawrence, KS ³	440
Do.	Pollock, LA ³	450
First Mississippi Corp. (Ampro)	Donaldsonville, LA ³	450
Green Valley Chemical Corp.	Creston, IA	35
IMC Fertilizer Group, Inc.	Sterlington LA	1,050
Jupiter Chemicals	West Lake, LA	30
LaRoche Industries Inc.	Cherokee, AL	175
Mississippi Chemical Corp.	Yazoo City, MS ⁵	500
Monsanto Co.	Luling, LA ³	490
Nitrogen Products, Inc.	Helena, AR ³	210
Occidental Chemical Corp.	Tacoma, WA	28
Pennwalt Chemical Co.	Portland, OR	8
Phoenix Chemical Co. ⁸	East Dubuque, IL	238
PPG Industries Inc.	Natrum, WV	50
J.R. Simplot Co.	Pocatello, ID	108
Sohio Chemical Co. (BP Intl Ltd)	Lima, OH ³	530

See footnotes at end of table.

TABLE 5—Continued
DOMESTIC PRODUCERS OF ANHYDROUS AMMONIA IN 1991

(Thousand short tons per year of ammonia)

Company	Location	Capacity ¹
Terra International, Inc.	Port Neal, IA	230
Do. (Oklahoma Nitrogen)	Woodward, OK	450
Triad Chemical Co. ²	Donaldsonville, LA ³	450
Union Chemical Co. (Unocal)	Kenai, AK	1,200
Wil-Grow Fertilizer Co. ⁴	Pryor, OK	94
Total		17,712

¹Engineering design capacity adjusted for 340 days per year of effective production capability.

²Plants purchased from Freeport-McMoRan Feb. 28, 1990.

³Revamp and/or retrofit.

⁴Plants purchased late May through early Nov. 1989 by Fertilizer Industries, holding company for the Sterling Group and Unicorn Venture Funds.

⁵Large 530,000-ton-per-year plant idle for more than 3 years reportedly dismantled.

⁶Wycon Chemical Co. assumed parent company's name, midyear 1989.

⁷Plant (140,000 tons per year) mothballed.

⁸Former N-Ren Corp. plants acquired by Great American Management and Investment, Aug. 1987.

⁹Joint venture between First Mississippi Corp. and Mississippi Chemical Corp..

Sources: Economics and Marketing Research Section, Tennessee Valley Authority. North American Fertilizer Capacity, Ammonia. Muscle Shoals, AL, Dec. 1991, and, Blue, Johnson and Associates. North American NPK Plants and Capacities. Foster City, CA, Jan. 1, 1992.

TABLE 6
CONSUMPTION TRENDS FOR MAJOR NITROGEN COMPOUNDS PRODUCED IN THE UNITED STATES¹

(Thousand short tons of contained nitrogen)

	1987	1988	1989	1990	1991 ^P
Fertilizer materials:					
Urea:					
Solid	1,904	2,028	*2,018	*2,085	2,060
Solution	1,137	1,201	1,232	*1,262	1,219
Total	3,041	3,229	*3,250	*3,347	3,279
Ammonium phosphates ²	2,296	2,591	*2,774	3,080	2,888
Ammonium nitrate:					
Solid	626	776	793	*768	706
Solution	1,012	1,193	*1,290	*1,229	1,216
Other ³	53	10	*-13	*-235	-
Total	1,691	1,979	2,070	*1,762	1,922
Ammonium sulfate:					
Synthetic and byproduct	460	490	*501	*533	468
Coke oven byproduct ⁴	51	59	60	*50	45
Total	511	549	*561	*583	513
Total fertilizer	7,539	8,348	*8,655	*8,772	8,602
Nonfertilizer materials:					
Urea:²					
Feed	142	171	193	*143	95
Industrial	237	241	239	*245	339
Total	379	412	432	*388	434
Ammonium nitrate ²	600	647	685	*716	*636
Nitric acid	460	463	478	*539	393
Acrylonitrile	337	340	344	400	350
Caprolactam	72	78	81	86	80
Total nonfertilizer	1,848	1,940	2,020	*2,129	1,893
Grand total ⁴	9,386	10,287	*10,675	*10,901	10,495

*Estimated. ^PPreliminary. ^RRevised.

¹Ranked in relative order of importance.

²Solid and solution.

³Unaccounted distribution.

⁴Data may not add to totals shown because of independent rounding.

Sources: Current Industrial Reports, MA28B and MQ28B, Bureau of the Census, and International Trade Commission.

TABLE 7
U.S. NITROGEN FERTILIZER
CONSUMPTION, BY
PRODUCT TYPE¹

(Thousand short tons nitrogen)

Fertilizer material ²	1990	1991 ^P
Single-nutrient:		
Anhydrous ammonia	3,800	4,155
Nitrogen solutions ³	2,267	2,246
Urea	1,715	1,558
Ammonium nitrate	603	626
Ammonium sulfate	184	172
Aqua ammonia	82	68
Other ⁴	177	194
Total	8,828	9,019
Multiple-nutrient:⁵	2,248	2,160
Grand total	11,076	11,179

^PPreliminary.

¹Fertilizer years ending June 30.

²Ranked in relative order of importance by product type.

³Principally urea-ammonium nitrate (UAN) solutions.

⁴Includes other single-nutrient nitrogen materials and all natural organics.

⁵Various combinations of nitrogen (N), phosphate (P), and potassium (K): N-P-K, N-P, and N-K.

Sources: Economics and Marketing Research Section, Tennessee Valley Authority. Commercial Fertilizers, Dec. 1991.

TABLE 8
U.S. PRODUCER STOCKS OF
FIXED NITROGEN COMPOUNDS
AT YEAREND¹

(Thousand short tons nitrogen)

Material ²	1990	1991 ^P
Ammonia	879	1,030
Nitrogen solutions ³	314	328
Urea	201	189
Ammonium phosphates ⁴	105	93
Ammonium nitrate	49	89
Ammonium sulfate	52	39
Total	1,600	1,768

^PPreliminary.

¹Calendar year ending Dec. 31.

²Ranked in relative order of importance.

³Urea-ammonium nitrate and ammoniacal solutions.

⁴Diammonium, monoammonium, and other ammonium phosphates.

Source: Current Industrial Reports, MA28B and MQ28B, Bureau of the Census.

TABLE 10
U.S. EXPORTS OF ANHYDROUS
AMMONIA, BY COUNTRY

(Thousand short tons ammonia)¹

Country	1990	1991 ^P
Australia	—	44
Belgium	101	88
Brazil	—	17
Canada	14	16
Chile	—	9
France	9	—
Korea, Republic of	300	361
Morocco	—	16
Netherlands	16	—
Norway	22	66
Philippines	—	20
South Africa, Republic of	178	124
Sweden	—	11
Other ²	6	5
Total	646	777

^PPreliminary.

¹Value data suppressed by Bureau of the Census. Ranked in relative order of importance by country and geographics.

²Eighteen countries principally in Latin America.

Source: Bureau of the Census.

TABLE 9
PRICE QUOTATIONS FOR MAJOR NITROGEN COMPOUNDS AT
YEAREND

(Per short ton product)

Compound	1990	1991
Ammonium nitrate: F.o.b. Corn Belt ¹	\$120-\$125	\$ 98-\$118
Ammonium sulfate: F.o.b. Corn Belt ¹	120- 130	107- 113
Anhydrous ammonia:		
F.o.b. Corn Belt	140- 145	125- 140
F.o.b. gulf coast ²	115- 118	105- 107
Diammonium phosphate: F.o.b. central Florida	145- 148	131- 135
Nitrogen solutions (28% to 32%):		
F.o.b. South Central ³	95- 99	86- 96
Urea:		
F.o.b. Corn Belt, prilled	155- 165	132- 145
F.o.b. gulf coast, granular ²	155- 156	129- 130
F.o.b. gulf coast, prilled ²	142- 145	121- 122

¹Ohio, Indiana, Illinois, Iowa, Missouri, and Nebraska.

²Barge, New Orleans.

³Alabama, Mississippi, Louisiana, Arkansas, Tennessee, Kentucky, and Texas.

Source: Green Markets, Fertilizer Market Intelligence Weekly, Dec. 24, 1990, and Dec. 23, 1991.

TABLE 11
U. S. IMPORTS OF ANHYDROUS AMMONIA, BY COUNTRY

(Thousand short tons ammonia)¹

Country	1990		1991 ²	
	Gross weight	Value ² (thousands)	Gross weight	Value ² (thousands)
Bermuda	—	—	12	\$1,401
Canada	1,220	\$122,525	1,132	117,636
Columbia	6	600	6	631
Kuwait	34	2,868	—	—
Mexico	505	52,242	343	38,501
Trinidad and Tobago	882	88,841	1,177	131,515
U.S.S.R.	³ 875	84,123	³ 1,005	101,138
Venezuela	61	5,786	—	—
Other ⁴	³ 3	² 201	2	241
Total	3,586	357,186	3,677	391,063

¹Preliminary. ²Revised.

¹Tonnage data suppressed by Bureau of Census effective Jan. 1, 1989. Reinstated Jan. 1, 1990, excluding U.S.S.R. Ranked in relative order of importance by country and geographics.

²Bureau of Census c.i.f. data.

³U.S. Bureau of Mines data.

⁴Six countries, principally Japan, in 1991.

Sources: Bureau of the Census, and U.S. Bureau of Mines.

TABLE 12
U.S. EXPORTS OF MAJOR NITROGEN COMPOUNDS IN 1991

(Thousand short tons)

Compound	Gross weight	Nitrogen content	Value ¹ (thousands)
EXPORTS			
Fertilizer materials:			
Ammonium nitrate ²	45	15	NA
Ammonium sulfate ²	828	174	NA
Anhydrous ammonia	777	639	NA
Calcium cyanamide	4	1	NA
Diammonium phosphate	10,734	1,932	NA
Monoammonium phosphate	848	93	NA
Nitrogen solutions	339	102	NA
Sodium nitrate	4	1	NA
Urea	1,180	543	NA
Mixed chemical fertilizers ³	239	37	NA
Other ammonium phosphates ⁴	66	11	NA
Other nitrogenous fertilizers ⁵	112	5	NA
Total⁶	15,177	3,553	NA
Industrial chemicals:			
Ammonia, aqua (ammonia content)	30	24	\$2,093
Ammonium compounds ⁷	5	1	7,799
Ammonium phosphate (ortho)	(⁸)	(⁸)	160
Potassium cyanide	(⁸)	(⁸)	817
Sodium cyanide	52	15	48,526
Other cyanides and cyanates	1	(⁸)	4,461
Hydrazine, hydroxylamine and related inorganic salts	16	8	27,793
Bismuth/silver nitrates	(⁸)	(⁸)	1,288
Potassium nitrate	18	2	5,492
Other nitrates	7	1	4,301
Nitric/sulfonitric acids	17	2	4,469
Nitrites	4	1	2,934
Total⁶	149	56	110,131
Grand total⁶	15,326	3,608	NA

NA Not available.

¹Export values f.o.b.

²Includes industrial chemical products.

³Harmonized codes 3105.10.0000 and 3105.20.0000.

⁴Codes 3105.51.0000, 3105.59.00, and 3102.70.0000.

⁵Codes 3101.00.0000, 3102.29.0000, 3102.60.0000, and 3102.90.0000.

⁶Data may not add to totals shown because of independent rounding.

⁷Carbonates, chloride, fluorides, and tungstate.

⁸Less than 1/2 unit.

Source: Bureau of the Census. Effective Jan. 1, 1989, U.S. exports and imports were reported under the new international Harmonized Commodity Description and Coding System (Harmonized System).

TABLE 13
U.S. IMPORTS OF MAJOR NITROGEN COMPOUNDS IN 1991

(Thousand short tons)

Compound	Gross weight	Nitrogen content	Value ¹ (thousands)
IMPORTS			
Fertilizer materials:			
Ammonium nitrate ²	464	156	\$52,771
Ammonium nitrate-limestone mixtures	1	(³)	102
Ammonium sulfate ²	343	72	29,111
Anhydrous ammonia ⁴	3,677	3,023	391,063
Calcium nitrate	(³)	(³)	8,763
Diammonium phosphate	8	1	2,197
Monoammonium phosphate	100	11	20,171
Nitrogen solutions	240	72	20,987
Potassium nitrate	25	3	6,894
Potassium nitrate-sodium nitrate mixtures	43	6	5,650
Sodium nitrate	139	22	16,292
Urea	1,785	821	209,322
Mixed chemical fertilizers ⁵	154	18	24,779
Other ammonium phosphates ⁶	52	8	7,384
Other nitrogenous fertilizers ⁷	130	25	26,614
Total⁸	7,159	4,240	822,102
Industrial chemicals:			
Ammonia, aqua (ammonia content)	8	2	797
Ammonium compounds ⁹	16	4	23,552
Calcium cyanamide	1	(³)	425
Potassium cyanide	1	(³)	1,343
Sodium cyanide	14	4	14,194
Other cyanides and cyanates ¹⁰	3	1	4,171
Hydrazine, hydroxylamine and related salts	2	1	5,965
Bismuth/silver nitrates	(³)	(³)	737
Strontium/other nitrates	4	1	3,721
Nitric/sulfonitric acids	11	2	2,914
Sodium/other nitrites	3	1	1,625
Total⁸	64	16	59,444
Grand total⁸	7,223	4,256	881,546

¹Import values c.i.f.

²Includes industrial chemical products.

³Less than 1/2 unit.

⁴Anhydrous ammonia tonnage data for U.S.S.R. in 1991; as reported by U.S. Bureau of Mines; includes industrial ammonia.

Tonnage data, excluding U.S.S.R., Bureau of Census.

⁵Harmonized codes 3105.10.0000 and 3105.20.0000.

⁶Codes 3105.51.0000, 3105.59.00 (exports and imports); 3102.70.0000 (exports); and 3105.40.0050 (imports).

⁷Codes 3101.00.0000, 3102.29.0000, 3102.60.0000, 3102.90.0000 (exports and imports); and 3105.90.0050 (imports).

⁸Data may not add to totals shown because of independent rounding.

⁹Carbonates, chloride, fluorides and tungstate (exports and imports); bromide, molybdate, orthophosphate, and perchlorate (imports).

¹⁰Data for code 2837.19.0020 (other cyanides) deleted or omitted by Bureau of Census. In 1989, 6,000 tons valued at \$5.7 million was reported.

Source: Bureau of the Census. Effective Jan. 1, 1989, U.S. exports and imports were reported under the new international Harmonized Commodity Description and Coding System (Harmonized System).

TABLE 14
WORLD ANHYDROUS AMMONIA
ANNUAL PRODUCTION
CAPACITY, DECEMBER 31, 1991

(Thousand short tons per year of ammonia)

Country	Rated capacity ¹
North America:	
Canada	4,000
United States	17,710
Total	21,710
Latin America:	
Argentina	120
Brazil	1,320
Colombia	190
Cuba	440
Mexico	3,290
Peru	180
Trinidad and Tobago	1,950
Venezuela	900
Total	8,390
Western Europe:	
Austria	570
Belgium	1,110
Finland	90
France	2,540
Germany:	
Eastern states	1,460
Western states	2,480
Greece	470
Iceland	10
Ireland	510
Italy	1,900
Netherlands	4,270
Norway	610
Portugal	340
Spain	990
Switzerland	60
United Kingdom	1,650
Total	19,060
Eastern Europe:	
Albania	100
Bulgaria	1,550
Czechoslovakia	1,210
Hungary	1,090
Poland	3,020
Rumania	5,120
U.S.S.R.	30,830
Yugoslavia	1,590
Total	44,510

See footnotes at end of table.

TABLE 14—Continued
**WORLD ANHYDROUS AMMONIA
 ANNUAL PRODUCTION
 CAPACITY, DECEMBER 31, 1991**

(Thousand short tons per year of ammonia)

Country	Rated capacity ¹
Africa:	
Algeria	1,130
Egypt	1,310
Libya	830
Nigeria	380
South Africa, Republic of	830
Zambia	90
Zimbabwe	70
Total	4,640
Asia:	
Afghanistan	80
Bangladesh	1,070
Burma	280
China	26,520
India	11,630
Indonesia	3,840
Japan	2,260
Korea, North	1,200
Korea, Republic of	950
Malaysia	410
Pakistan	1,680
Taiwan	340
Vietnam	70
Total	50,330
Middle East:	
Abu Dhabi	380
Bahrain	550
Iran	1,250
Iraq	—
Israel	90
Kuwait	—
Qatar	670
Saudi Arabia	1,190
Syria	380
Turkey	500
Total	5,010
Oceania:	
Australia	700
New Zealand	100
Total	800
Total world²	154,450

¹Includes capacity at operating plants as well as plants on standby basis. Rated capacity based on 340-day-per-year effective operation.

²Data may not add to total shown because of independent rounding.

Sources: Branch of Industrial Minerals, U.S. Bureau of Mines, and International Fertilizer Industry Association (IFA).

TABLE 15
AMMONIA: WORLD PRODUCTION, BY COUNTRY¹

(Thousand short tons of contained nitrogen)

Country	1987	1988	1989	1990	1991*
Afghanistan*	44	44	44	44	44
Albania*	105	110	120	110	90
Algeria	192	217	145	*150	165
Argentina	*89	86	82	77	70
Australia	456	425	379	425	460
Austria	*495	450	452	*452	440
Bahrain	304	340	327	352	360
Bangladesh	480	742	854	*772	740
Belgium	296	402	322	*330	330
Brazil	1,049	1,031	1,079	1,034	875
Bulgaria	1,180	1,480	*1,430	*1,443	1,435
Burma	130	*124	*132	*138	140
Canada	3,182	3,626	3,681	*3,366	3,325
China*	*17,640	*18,190	*18,740	*19,290	19,840
Colombia	98	93	101	108	100
Cuba	164	149	147	*165	165
Czechoslovakia	855	850	878	874	610
Egypt	870	869	802	*810	930
Finland	55	47	46	26	20
France	2,237	*2,019	*1,627	1,748	1,770
Germany, Federal Republic of:					
Eastern states	1,296	1,274	*1,270	*1,100	NA
Western states	2,129	2,011	*1,909	*1,842	NA
Total	3,425	3,285	*3,179	*2,942	2,590
Greece	280	290	267	283	230
Hungary	867	763	742	*491	320
Iceland	10	10	*10	*10	10
India ²	5,842	6,840	7,342	7,741	7,765
Indonesia	2,606	2,609	2,785	*2,900	2,755
Iran	131	160	370	463	*516
Iraq*	66	345	*522	*364	45
Ireland	440	460	425	435	475
Israel	68	63	*66	*53	40
Italy	1,582	1,721	1,594	1,320	1,265
Japan	1,715	1,680	1,696	1,688	*1,712
Korea, North*	500	550	550	550	605
Korea, Republic of	523	558	529	*453	450
Kuwait	637	530	733	322	—
Libya	386	239	234	*220	220
Malaysia	354	331	307	252	*315
Mexico	1,922	2,279	2,315	2,385	2,450
Netherlands	2,521	*2,975	*3,203	*3,521	3,310
New Zealand	80	80	77	77	77
Nigeria	142	342	330	367	330
Norway	383	467	421	475	425
Pakistan	1,300	1,293	*1,295	*1,300	1,305
Peru*	88	105	*100	*100	100

See footnotes at end of table.

TABLE 15—Continued
AMMONIA: WORLD PRODUCTION, BY COUNTRY¹

(Thousand short tons of contained nitrogen)

Country	1987	1988	1989	1990	1991 ^a
Poland	2,400	2,577	² 2,601	² 2,211	1,840
Portugal	171	210	167	218	215
Qatar	618	657	647	⁸ 838	770
Romania ^a	³ 3,073	3,090	2,870	2,100	1,245
Saudi Arabia	702	956	952	1,039	910
Somalia ^a	8	—	—	—	—
South Africa, Republic of	603	520	502	503	⁵ 504
Spain	495	525	608	533	520
Sweden	37	—	—	—	—
Switzerland ^a	43	35	35	35	35
Syria	102	87	135	114	115
Taiwan	² 269	307	² 223	² 238	² 268
Trinidad and Tobago	1,243	1,528	¹ 1,670	1,676	1,760
Turkey	364	³ 340	⁴ 416	⁴ 452	355
U.S.S.R.	22,050	22,270	² 21,384	² 20,062	18,850
United Arab Emirates	343	330	357	322	315
United Kingdom	1,560	1,218	1,143	1,270	955
United States ⁴	13,232	13,827	¹ 13,536	¹ 13,806	³ 13,991
Venezuela	578	621	587	⁷ 714	550
Vietnam	40	40	⁴ 40	⁴ 40	40
Yugoslavia	1,033	946	750	⁸ 884	770
Zambia	37	18	13	⁴ 4	5
Zimbabwe	59	71	68	76	76
Total	¹104,849	¹109,442	¹109,184	¹107,561	103,308

^aEstimated. ²Revised. NA Not available.

³Table includes data available through May 20, 1992.

⁴Data are for years beginning Apr. 1 of that stated.

⁵Reported figure.

⁶Synthetic anhydrous ammonia; excludes coke oven byproduct ammonia.

TABLE 16
WORLD ANHYDROUS AMMONIA SUPPLY-DEMAND RELATIONSHIPS¹

(Million short tons nitrogen)

	1986	1987	1988	1989	1990	1991 ^P	1992 ²	1993 ²	1994 ²	1995 ²	1996 ²
Capacity ³	123.5	124.1	127.7	129.1	127.7	126.9	130.0	131.3	134.7	137.5	138.1
Demand: ⁴											
Fertilizer	89.2	93.3	97.8	97.5	95.8	91.8	93.4	96.6	98.7	100.9	103.0
Industrial	11.2	11.5	11.6	11.7	11.8	11.5	11.6	11.7	11.8	11.9	12.0
Total ⁵	100.4	104.8	109.4	109.2	107.6	103.3	105.0	108.3	110.5	112.8	115.0
Operating rate ⁵	81%	84%	86%	85%	84%	81%	81%	82%	82%	82%	83%
Consumption:											
Pounds per capita ⁶	41.0	41.9	42.9	42.0	40.6	38.3	38.2	38.7	38.8	38.9	39.0
Population:											
Billion ⁷	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9

^PPreliminary. ^RRevised.

¹Calendar years.

²Forecast.

³Design capacity, 340-day-per-year effective operation.

⁴Ammonia consumed in the production of fertilizer and industrial products, including process losses.

⁵Total demand as a percent of design capacity.

⁶Ammonia demand expressed in pounds per person.

⁷Statistical Abstract of the United States 1990; Bureau of the Census.

Source: Division of Mineral Commodities, Branch of Industrial Minerals, U.S. Bureau of Mines.

NONRENEWABLE ORGANIC MATERIALS

By Michele R. Simmons and Thomas D. Kelly

Mrs. Simmons, industrial program manager with the Branch of Materials of the U.S. Bureau of Mines, directs work in the analysis of the petroleum, petrochemical, and plastic industries as related to the application of nonrenewable organic materials in major industrial sectors. Mr. Kelly, materials specialist in the Materials Engineering Group at the Minerals Availability Office of the U.S. Bureau of Mines, has over 6 years of experience in the petroleum industry. Some of the data were prepared by John Sznopke, materials specialist in the Materials Engineering Group at the Minerals Availability Field Office.

Nonrenewable organic materials obtained from natural gas-, coal-, and petroleum-derived feedstocks are used in a wide variety of durable and nondurable goods. Plastics, synthetic fibers, and synthetic rubber are important products made from nonrenewable organic feedstocks that traditionally are used primarily as fuels. In addition, lubricants, asphalt, road oil, waxes, and numerous other petrochemicals, also derived from organic feedstocks, fulfill many important nonfuel uses. Products made from these nonrenewable organic materials include such varied items as household goods, eyewear, textiles, tires, engine grease, paving materials, pharmaceuticals, medical devices, and other items vital to society's well-being.

In 1991, consumption fell in three of the four principal nonrenewable organic materials use categories. Chief reasons behind such lackluster performance can be traced to the economic recession, growing environmental concerns, and increases in crude oil prices during the year. Examination of these categories reveals that consumption in the petrochemical industries category grew 12% in 1991 to 73.0 million metric tons. In the lubricants, waxes, and miscellaneous products category, consumption declined 5% to 11.7 million tons. In the petroleum coke and coal category, consumption declined 2% to 8.4 million tons, and in the asphalt and road oil category, consumption decreased 2% to 26.6 million tons.

DOMESTIC DATA COVERAGE

The U.S. Bureau of Mines collects no original data on organic materials use from company surveys. All of the statistical information included in this report was obtained from outside sources. Much of it relies on data collection efforts of other Government agencies and on surveys conducted by various industry publications and materials industry trade associations. The intent of the Bureau is not to duplicate the efforts of those organizations, but to augment those efforts with both data analysis and collection where adequate coverage is not currently available.

The data were obtained from a variety of sources, including the Annual Energy Review 1991 from the Energy Information Administration, U.S. Department of Energy; the Department of Commerce; and a wide variety of industry contacts. In addition, data were obtained from the Society of the Plastics Industry, Inc.; several industry trade associations; other Government data publications; and many industry trade journals, especially, Chemical & Engineering News, Plastics News, and Modern Plastics. The focus of the discussion is primarily on plastics, synthetic fibers, and synthetic rubber. The synthetic fiber data were based on the efforts of Chemical & Engineering News, on surveys conducted by the Fiber Economics Bureau, Inc. and by various industry publications, and materials from the American Fiber Manufacturers

Association, Inc. Data for synthetic rubber were based on reports in the Chemical & Engineering News, Chemical Week, the International Institute of Synthetic Rubber Producers, and the Rubber Manufacturers Association. Other categories of organic materials use are covered as well, but the same level of detailed information is not generally available for them; therefore, little additional detail was provided.

BACKGROUND

At the beginning of the 20th century, the United States satisfied about 59%, in constant dollars, of its material needs from renewable resources. The remaining 41% was met by metals and minerals. The traditional primary renewable resources are agricultural (cotton, oils, etc.), forest (lumber, etc.), and wildlife (furs, etc.) products. Primary nonrenewable resources are inorganic minerals and organic materials derived from coal, petroleum, and natural gas. This pattern of use changed considerably during the years up through mid-century and somewhat less so in later years, as major shifts in feedstock reliance occurred. The first shift marked a decrease in percentage share of material needs obtained from renewable sources, which fell to about 38% in 1950, then to about 26% by 1989. The second major change was the increased use of nonrenewable organic feedstocks in the production of asphalt, plastics, synthetic rubber, synthetic fibers, and

petrochemicals. This trend is shown in figure 1, which displays the relative market shares for competing material feedstocks. Individual data for primary and secondary metals are not available prior to 1935. (This figure is an update based on work by Spencer, et al.¹) (See figure 1.)

Products for Trade and Industry

Only a small amount of the total U.S. consumption of oil, gas, and coal goes to nonfuel uses, compared to the amount of nonrenewable organic resources used for fuels. In 1991, total petroleum products supplied for domestic use, in commonly reported units, amounted to 6.1 billion barrels; 895 million barrels was for nonfuel purposes, of which 284 million barrels was used for such purposes as asphalt and road oil, lubricants, petroleum coke, waxes, and miscellaneous products. The remainder, 611 million barrels, included liquefied refinery gases (LRG's), natural gas liquids (NGL's), petrochemical feedstocks, and naphthas used by the chemical industry. U.S. consumption of natural gas was 19.6 trillion cubic feet in 1991. A total of 596 billion cubic feet of natural gas, primarily methane, went into nonfuel end uses.²

The portion of total U.S. consumption of nonrenewable organic materials that goes into nonfuel uses is often reported in terms of British thermal units (Btu's) or value. Measured in Btu's, it has been approximately 6% for the past several years,³ but when measured in value terms, the proportion is higher. Fraser⁴ calculates that, in value terms, the portion of organic materials consumed in nonfuel uses during the 1980's has been between 8.5% and 10%. He points out that because nonfuel uses consume higher priced petroleum and natural gas, instead of lower valued coal, the value of organic materials going into nonfuel uses is understated when measured in Btu's.

Petroleum products, including NGL's, accounted for approximately 87% of the Btu's from fossil fuels consumed for nonfuel uses in 1991. Asphalt and road oil, lubricants, petroleum coke, wax, and

miscellaneous products, as a subgroup of petroleum products, comprised approximately 41% of total petroleum products used for nonfuel purposes. Natural gas, principally methane, accounted for approximately 12% of the Btu's from the fossil fuels consumed; nearly two-thirds of that was used as feedstock for the production of ammonia-based fertilizers. Coal accounted for the remainder.⁵

A simplified overview of nonrenewable organic materials from well to feedstocks is shown in figure 2.⁶ During the processing of natural gas, NGL's are extracted from wet gas, producing dry gas, or methane. Methane and NGL's are also primarily consumed as fuels. In addition to their fuel uses, however, they are also the principal sources of petrochemical feedstocks used to make resins, fibers, elastomers, adhesives, paints, and pharmaceuticals.

Among the many products of the petroleum refining process are naphthas and LRG's. These are also sources for petrochemical feedstocks, but both are primarily consumed as fuels. Naphthas are a primary constituent of gasoline, and LRG's have a variety of fuel uses. (See figure 2.)

The array of petroleum products produced at a refinery is dependent on a number of factors, including the design of the plant facilities, the characteristics of the petroleum refined, economics, and Government regulations. Crude petroleum varies from source to source, and thus the range of products that can be produced economically also varies. The cost differential to produce one product instead of another and the prices received for the products dictate the economically efficient array of products. Governments can also influence the product array through specifying defense needs or by rationing resources during shortages. The chemical industry, in particular the plastics sector, had limited access to feedstock materials during the oil crisis of the early 1970's, for example.

Lubricating oils are a combination of a small number of crude oil-base stocks blended with a large number of additives. The additives are used to give specific

properties to a wide variety of lubricating oils. These properties include viscosity, viscosity change with temperature, oxidation resistance, acidity, boiling temperature, and pour point.

Petroleum coke comes in three forms. Sponge coke varies from a hard, porous, irregular-shaped lump to a fine powder. It is used in production of pure carbon or artificial graphite used for motor brushes, structural graphite, and dry cells. Needle coke, with its name derived from its shape, is the preferred material for graphite electrodes because of its lower electrical resistivity and lower coefficient of thermal expansion. Shot coke, which is generally produced unintentionally and comes only from residuals of California crude oils, has a variety of uses as carbon or graphite. The nonfuel uses of coal are mainly for its carbon content; it is used as a filter material for boiler water, for example, where it takes out organic contaminants. Coal is also used in the production of cyclic intermediates that feed into the petrochemical feedstocks area.

Asphalt, a product of petroleum refining, is generally the bottom product left after all other products have been taken out. It is always blended with cutter stock, similar to kerosene but with a lower flash point, into three grades: fast cure (less of the kerosenelike material added so it sets up faster), medium cure, and slow cure, for use as road base at different ambient temperatures.

Not all refinery operations produce asphalt. Many refineries are set up to handle light crude oils, and the bottom product is a fuel oil. Asphalt is a natural product only from heavy crude oils, and the amount of asphalt produced will be in rough proportion to the gravity of the crude oil. Further processing is necessary to make the asphaltic material suitable for roofing applications.

Waxes, also a natural product of the refining processes, are derived from the gas oil fraction in the distillation process. Waxes come out of all crude oils. If the crude oil contains a large proportion of wax, then the final "pull" becomes unsuitable for asphalt production, even if it is a heavy crude oil.

Petrochemical feedstocks are the raw materials from which plastics, synthetic fibers, and synthetic rubber are produced. Other significant uses for petrochemical feedstocks are for solvents, paint thinners, and cyclic intermediates that are further processed into dyes, medicinal chemicals, and pesticides. Figure 3 is a simplified flow chart of plastic resins produced further downstream beginning with some basic petrochemical building blocks. (See figure 3.)

Table 1 reports the amounts of selected feedstocks and the relative percentage of total consumption of each feedstock consumed in the production of plastics. Ethylene dominates plastics feedstock consumption, with 26.5 billion pounds consumed. Three quarters of ethylene and benzene consumption, 65% of naphthalene (derived from coal tars), 64% of propylene, and 22% of xylene were consumed in the production of plastics in 1990. Although plastics are the primary use for some feedstocks, they are only a minor use for others. Only small percentages of toluene, butadiene, and methane were used in the production of plastics. (See table 1.)

Methane is used to produce fluorocarbons and produces methanol that, in turn, is used in the production of phenolics. Ethane and propane can each be used to produce ethylene or propylene. Ethylene is used in the production of numerous resins, including polyethylene, fluorocarbons, polyesters, and acrylonitrile-butadiene-styrene (ABS). Propylene is used in the production of resins such as polypropylene, polyesters, acrylics, and polyurethane. Butane is used in the production of ABS and some vinyls. Naphtha is the source of benzene, toluene, and xylene. Benzene is used in the production of unsaturated polyesters (nylon), polysulfone, styrene, and phenolics. Toluene and xylene are used in the production of polyurethanes and polyesters.

Economic Factors

The major sources of petrochemical feedstocks are crude oil and NGL's. And throughout the world, naphtha, a crude

oil fraction, is the main source for ethylene and propylene, the primary olefins involved in plastic resin production. In nations rich with natural gas, there has been a long-term trend to use less naphtha and more NGL's as sources of these olefins. In the United States, NGL's are the major sources of these primary olefins. However, naphtha remains the major worldwide source of benzene.

World crude oil production decreased by 0.9% to 60.0 million barrels per day in 1991.⁷ The decline in production resulted from war damage in Kuwait, sanctions imposed by the United Nations on oil exports from Iraq, and continuing equipment-related production problems in the former U.S.S.R.

The price of crude oil, reflecting market uncertainties during the year, exhibited a number of turnabouts. During the week of January 4, 1991, crude oil was priced at \$24.24 per barrel. Immediately following the end of the Persian Gulf war the price of crude oil fell to a 1991 low of \$15.34 per barrel the week of March 4, 1991. In the following months, the price of crude oil eased up slightly, but fell again in July, before gradually easing upward during the next several months. By September, crude oil had reached about \$19.17 per barrel and continued upward to \$20.18 per barrel in October as refiners increased stocks in preparation for winter demand. In November, however, the price of crude oil dropped to \$19.72 per barrel and continued to slip in December to \$17.56 per barrel. (Reported monthly crude oil prices represent U.S. refiner composite acquisition costs.)⁸

Petrochemical feedstock prices remained up in January 1991, as crude oil prices rose in the days leading up to the Persian Gulf war (table 2). Soon after war began, petrochemical feedstock prices, following crude oil prices, fell and continued to move lower. Factors that contributed to this easing in prices include a sharp drop in the price of crude oil following a successful U.S. and allied forces air campaign against the Iraqi military, lower demand for end products as the U.S. economy continued to

weaken, and ample available petrochemical feedstocks inventories.

By July 1991, prices for feedstocks were down considerably. In the remaining months of the year, feedstock prices had exhibited a mixed pattern, as some prices began moving upward and others hovered near, or fell farther from, prices posted just months earlier. (See table 2.)

Operating Factors

The economic recession affected industrial employment in the organic materials sector during the year. Total industrial employment in the plastics, synthetic fibers, and synthetic rubber category fell by about 2% to 177,000 workers in 1991, compared with 181,000 workers a year earlier. This decline was reflected in the number of male employees for the year; the number of women employees remained unchanged. The decline in employment was more severe for production workers, where the number of workers fell by 5% to 110,000 in 1991, compared with 116,000 in 1990. The average workweek increased by 0.1 hours. Average hourly earnings were up 4.3%, more than the 3.1% increase for all manufacturing. (See table 3.)

No separate accounting of the total number of employees producing feedstocks for organic materials is possible. Nonfuel uses of fossil fuels account for only 6% to 8% of the total on an energy content basis. Employment in the overall oil and gas sectors, the industries that are the source for most organic materials feedstocks, was up slightly in 1991. Oil and gas extraction showed a 0.3% decrease in employment, while petroleum refining and gas production and distribution had employment increases of about 2% and 1%, respectively. Asphalt paving and roofing materials employment declined by almost 4%.⁹

ANNUAL REVIEW

U.S. production of primary materials from nonrenewable organic resources during 1991 increased in all categories,

except one (table 4). For the petrochemical industries category, total feedstocks production increased almost 13% to 65.1 million tons. Production of resins, a subcategory of petrochemical industries composed of plastics, synthetic fibers, and synthetic rubber, increased a little more than 1% to 27.3 million tons in 1991. Imports decreased from 10.1 million tons in 1990 to 8.9 million tons in 1991. Exports fell 42% to 1.3 million tons in 1991. Apparent primary consumption increased slightly more than 12% to about 73.0 million tons in 1991. ("Apparent primary consumption," as used here, measures supply and disposition of organic materials from primary sources and equals production plus imports minus exports plus stock changes. Recycled materials are not accounted for in this calculation.) The price for feedstocks shown in the table represents the price of the organic material that is used to make these products and not the price of the products themselves. It reflects changes in the price of energy and, consequently, fluctuates with energy markets. (See table 4.)

Production of lubricants, waxes, and miscellaneous products decreased to 12.1 million tons in 1991. Imports fell to 580,000 tons for the year, from 740,000 tons in 1990. Exports decreased almost 13% to about 1.0 million tons in 1991. Apparent primary consumption decreased 5% to 11.7 million tons.

Production of petroleum coke and coal rose slightly to 13.1 million tons in 1991. Imports, remaining unchanged from those of a year ago, stood at 40,000 tons. Exports fell slightly to 4.6 million tons. Yearend stocks rose 27% to 520,000 tons. Apparent primary consumption decreased 2% to 8.4 million tons. It should be noted that data for coal were included in production, but not in imports, exports, or stocks because of lack of detailed information on coal not used as a fuel.

Production of asphalt and road oil increased almost 3% to 25.7 million tons in 1991. It has fluctuated between 24 million tons and 27 million tons since 1986. Imports decreased 13% to 1.7

million tons in 1991, from 1.9 million tons a year earlier. Exports increased 12% to 190,000 tons for the year. Yearend stocks rose 19% to 3.7 million tons. Apparent consumption decreased almost 2% to 26.6 million tons in 1991.

The economic recession stifled most activities within the chemical industry, from basic petrochemical feedstock inputs and primary downstream outputs to employment and earnings. Nevertheless, the chemical industry managed to fare somewhat better than manufacturing overall, which fell by 3% from that of a year ago. In 1991, overall production of chemicals remained essentially unchanged from the 1990 level, as the production of organic chemicals rose a modest 2% and that of inorganic chemicals dropped 1%. However, as a result of reduced economic activity and weak demand for most chemicals across key domestic markets, U.S. chemical producers looked to foreign markets, and to build up domestic chemicals inventories, which rose 2% for the year, in anticipation of a recovery in chemical demand. U.S. chemical trade with most regions remained strong, making 1991 an extraordinary trade year for chemical exports and imports. Separately, chemical exports increased 10% in 1991, reaching a new high of about \$43 billion. Chemical imports also set a new high, increasing 8% to about \$24.2 billion. The resulting chemical trade surplus, which totaled \$18.8 billion, marked an alltime high as well. Even with favorable chemical trade in 1991, the U.S. chemical industry saw chemical sales and profits decline overall from those of a year ago, as did earnings, capital spending, and employment.¹⁰

The chemical industry increased downstream production of plastics, synthetic fibers, and synthetic rubber in 1991. Taken separately, production of plastics increased by 3% overall, mainly due to strong growth in thermoplastic polyethylene and thermoplastic polyester.¹¹ Domestic demand for plastics dropped 1% for the year, to 27.5 million tons.¹² Plastics exports rose considerably in 1991, in contrast to imports, which fell.

Production of synthetic fibers increased overall by 1% in 1991 due to production gains in polyester and polyolefins. Production of synthetic rubber decreased overall by 4%, with ethylene-propylene, down 13% from that of a year ago, posting the biggest loss.¹³

World Review

In 1991, chemical industries worldwide experienced downturns in most activities as many nations faced the pressures of economic recession or experienced slower growth. Other factors that affected industry were the Persian Gulf war and its impact on crude oil supplies and prices; environmental mandates; evolving international trade trends; and the disintegration of the U.S.S.R., the world's leading crude oil supplier. Together, these factors for many nations resulted in industry uncertainty and bleak market performance.

Events leading up to the Persian Gulf war brought about increases in the price of crude oil early in the year as uncertainties emerged surrounding the availability of future Iraqi and Kuwaiti oil supplies. These crude oil price increases were reflected in the prices of petrochemical feedstocks and raw materials consumed by the chemical industry. Chemical industry suppliers, however, encountered difficulty in passing along product price increases to their customers-processors and end-product manufacturers, which further eroded supplier's profit margins. In addition, customers changed their product purchasing strategy as they began using more of their own inventories as a hedge against future supply price increases. Replacement of lost Iraqi and Kuwaiti crude oil supplies to world markets by other oil-producing nations and reaction to military successes against Iraq helped ease oil supply concerns and prices and, in turn, petrochemical feedstocks prices.

International trade negotiations continued to make headlines during the year. For the United States, international trade is an important component of the U.S. chemical industry, yielding one of the biggest trade surpluses in the United

States. In 1991, talks continued in attempts to establish a North American Free Trade Agreement (NAFTA). The agreement is intended to open up markets among Canada, Mexico, and the United States and at the same time, enable them to better compete in a global market. Among the major issues of concern to the U.S. chemical industry are future feedstocks, access to markets, and investments. U.S. chemical trade with Mexico has been growing and, while the volume of trade with Mexico is considerably less than that with Canada, future export opportunities are promising. (The United States and Canada have had a free trade agreement in effect since 1989 to eliminate all tariffs on U.S. and Canadian goods by January 1998 and reduce or eliminate many nontariff barriers.) Discussions also continued toward a General Agreement on Tariffs and Trade (GATT), which is expected to have a major impact on the volume of chemicals traded worldwide due to the reduction of tariffs and nontariff barriers and the elimination of import quotas.

Environmental concerns and regulations remained in the forefront during the year, as the 1990 Clean Air Act Amendments, benzene regulations, and other new regulations could result in chemical plant modifications for waste treatment and pollution control worldwide. The United States has had in place a Toxic Release Inventory program since 1987 that tracks domestic sources and types of toxic chemical releases into the air, land, and waters. Under this program, emissions of more than 300 toxic chemicals are monitored, including such chemical precursors to plastic resins as ethylene, propylene, and benzene. This program has attracted international attention, particularly as a vehicle for determining pollution prevention opportunities.

Reauthorization of the Resource Conservation and Recovery Act (RCRA) did not occur in 1991. The proposed legislation seeks, among other things, to encourage the manufacturing sector to produce less waste and for companies to recycle more of the waste they produce.¹⁴ The impact of RCRA on the plastics

industry is expected to be far-reaching because it governs a host of solid waste issues, including environmental labeling, recovery rates and recycled-content requirements, and toxic metals in packaging.¹⁵

With the disintegration of the U.S.S.R., individual Republics will need to critically assess the current state of their economies and the major elements within to ensure a healthy survival and to attract foreign investment and encourage privatization efforts. This will undoubtedly lead to a closer look at their chemical industries and the availability of domestic resources directed to those industries and their outputs. At present, those outputs are largely basic chemicals and not specialty consumer products, such as soaps and pharmaceuticals. Plans for change in this sector will likely emerge over the coming years, moving closer to self-sufficiency and ensuring a viable industry.

The chemical industry, itself global in scope, will likely undergo pivotal changes in the months, and years, ahead as some nations begin to restructure or reform their segments, to upgrade product capabilities, and to increase services to expand their markets.

The next several sections highlight activities of various foreign chemical industries in 1991. This information is based largely on data from Chemical & Engineering News' annual statistical compilation of facts and figures for the chemical industry.¹⁶

Canada.—Economic recession restrained growth in Canada in 1991. That factor led to widespread declines throughout the chemical industry and in manufacturing overall. Chemical producers in general saw production fall in all areas, except in specialty markets such as pharmaceuticals and toiletries. Chemical prices overall posted a modest increase over the year-earlier level. In global trade, chemical exports overall decreased by 2%, while chemical imports overall increased by 1%—causing an existing chemical trade deficit to worsen.

Chemical production of plastics decreased overall by 6% in 1991. This

decrease resulted from lower domestic demand for plastics across most key markets from that of a year ago. High-density polyethylene production, however, rose an impressive 26%, in contrast to low-density polyethylene production, which fell 5%. Plastics exports rose as producers sought foreign markets for their products. Plastics imports declined from those of a year ago.

Japan.—In 1991, a slowing Japanese economy resulted in limited growth throughout the chemical industry and in manufacturing overall. In general, chemical producers posted gains in production of most chemicals for the year, but saw chemical sales slip. More disappointing to producers, however, were the considerably lower earnings and profits realized compared to those of a year earlier. In global trade, Japanese chemical exports and chemical imports rose by 10% and 8%, respectively.

Chemical production overall increased by a modest 2% in 1991, due largely to strong growth in certain organic chemicals. Production of plastics overall grew by 1% for the year, although polyethylene exhibited stronger growth (3%). Synthetic fibers also grew by 1% from those of a year ago, but synthetic rubber declined by 4%.

Western Europe.—The nations of Western Europe struggled to recover from economic slowdowns that curtailed growth throughout the chemical industry in 1991. The major chemical-producing nations, such as Germany (composed of state data for West Germany only), France, and the United Kingdom, fared better than their counterparts, by comparison. For those nations, chemical producers saw modest increases in sales and prices over year-earlier levels. Those same producers experienced moderate growth in chemical production, capital spending, and employment. In other nations, producers saw continued declines or mixed patterns of growth in those areas.

Chemical production throughout Western Europe was dominated by inorganic and organic products (including fertilizers) in 1991 and, to a lesser extent, by plastics, synthetic fibers, and synthetic rubber. Compared to a year ago, overall production of plastics declined, despite the encouraging gains in commodity plastics posted by some nations. Overall production of synthetic fibers and synthetic rubber also declined in 1991. For plastics and synthetic rubber, the large-volume producers were France and Germany. For synthetic fibers, Germany, Italy, and the United Kingdom were the large-volume producers.

Eastern Europe.—The nations of Eastern Europe, hampered by economic recession, posted an overall decline of 19% in industrial production in 1991. This marks the third consecutive drop, each more severe than the last, in industrial output in the past 3 years. Each of the Eastern Europe nations (i.e., Albania, Bulgaria, Czechoslovakia, Hungary, Poland, Romania, and Yugoslavia) contributed to this drop, with separate declines in industrial output ranging from 11.9% to 27.8%.

Chemical production also continued to decline in the Eastern European nations in 1991. Several nations, namely, Bulgaria, Poland, and Romania, even saw production losses exceed those of industry overall. Registering the biggest losses in chemical production from that of a year ago were Bulgaria, with 34%, Czechoslovakia, with 25%, and Romania, with 20%. Production in Eastern Europe was dominated by basic chemicals. On a component basis, the production of plastics, synthetic fibers, and synthetic rubber each accounted for a considerably smaller share of total chemical production compared to chemical fertilizers. Nevertheless, supplies throughout the region were down in nearly all categories from those of a year ago, and, in some cases, by more than 20%.

U.S.S.R.—In 1991, the economy of the U.S.S.R. was also restrained by recession. The gross national product fell

by about 15% in 1991 from that of a year ago; overall industrial production fell by about 8%, and chemical production fell by about 10%.

The chemical industry exhibited production declines in nearly all chemicals in 1991, although some declines were more substantial than others. For those chemicals, the production declines experienced only continued a downward trend set in motion more than 2 years ago. The U.S.S.R.'s chemical industry has long produced large amounts of agricultural chemicals, chemical fertilizers, and sulfuric acid and, by contrast, produced much smaller amounts of plastics, synthetic fibers, synthetic rubber, and other downstream chemical products. In 1991, plastics production fell by 12% to 4.0 million tons. Total synthetic fibers production, composed of both cellulosic and noncellulosic fibers, decreased by 20% to 1.2 million tons in 1991.

With the disintegration of the U.S.S.R., the chemical industry will no longer continue to function in the years ahead as it once did. Each Republic will be forced to examine the various segments of its chemical industry and restructure or reform each as necessary to help ensure a viable industry and to encourage capital investment and future profits. For many of the Republics, this could result in substantial changes to their current chemical industry infrastructure as well as to their product slate.

Pacific Basin.—**South Korea.**—Overall manufacturing grew by 9%, and shipments grew by 11% in 1991. During that same period, overall production of chemicals, petroleum, coal, rubber, and plastic products rose by 12% and overall shipments, by 18%. In global trade, chemical exports increased 27% to \$3,191 million, and chemical imports increased by 12% to \$8,289 million. The increase in chemical exports, however, was not enough to shrink the existing chemical trade deficit, which widened by 4% to \$5,098 million.

Plastics production of polyethylene, polypropylene, and polystyrene posted dramatic gains in 1991. For the year,

polyethylene production rose by 38%; polypropylene, 35%; and polystyrene, 28%. Overall production of plastic products increased by 6% from those of a year ago, and shipments grew by 4%.

Production of rubber products decreased overall by 4% and shipments by 3% for the year.

Australia.—Chemical production overall decreased in 1991, with very few chemicals registering gains amid the general downturn. Chemical exports overall rose by 6% to \$1,082 million, due largely to healthy growth in exports of medicinal products. Chemical imports overall decreased by 2% to \$3,986. However, imports of plastics and polymers in particular dropped by 10%. The overall increase in chemical exports brought about a reduction in the existing chemical trade deficit, which stood at \$2,904 million for the year.

China.—Chemical production in most areas exhibited strong growth in 1991. In particular, production of plastics jumped 17% to 2.6 million tons; synthetic fibers grew 12% to 1.9 million tons; and synthetic rubber rose 6% to 0.34 million tons. In foreign trade, chemical exports overall grew a modest 2% to \$3,818 million for the year. In contrast, chemical imports overall registered a dramatic increase of 40% to stand at \$9,277 million. In particular, imports of plastic materials; i.e., resins, cellulose esters, and ethers, jumped 59% to \$2,378 million in 1991.

Taiwan.—Overall production of chemical materials (i.e., basic chemicals, petrochemicals, fertilizers, synthetic fibers, plastics, and resins) grew by 15% in 1991. In particular, production of plastics and resins rose by 19%, and synthetic fibers grew by 21%. Production of chemical products overall grew by 9% for the year. In foreign trade, chemical exports overall increased by 18% to \$6,743 million in 1991, and chemical imports overall grew by 23% to \$9,344 million.

OUTLOOK

Global trade patterns are expected to change as substantial investments in resin capacity are made over the coming years. Huge increases in polyolefin resin capacity for the Far East, and Republic of Korea in particular, have already been scheduled. In the Far East, olefin monomer capacity is expected to rise at least 90% from 1990 to 1995 to more than 22 billion pounds per year (lb/yr). The ethylene and propylene coming from that capacity will mainly be used to make polyethylene and polypropylene. In the Republic of Korea, low-density polyethylene capacity is expected to rise at least 80% from that of 1990 to 2.06 billion lb/yr by 1995 and high-density polyethylene capacity at least 40% to 2.34 billion lb/yr. Polypropylene capacity is expected to increase by 1 billion lb/yr from 1991 to 1993. Moreover, Japan last year announced plans for capacity increases totaling 4.73 billion lb/yr of ethylene, 1 billion lb/yr of polyethylene, and at least 175 million lb/yr of polypropylene due on-stream in the next several years, but has since postponed or canceled some of them because of concerns about rising capacity in the region and the sluggish economy. The new capacity is expected mainly to help fulfill increasing local demand requirements of newly industrialized countries in the Far East. But so far, growth in demand has lagged growth in capacity. In addition, large polyolefin plants are being built in Indonesia, Malaysia, and Thailand. During the near term, this scheduled new capacity, together with existing capacity, could keep prices for these resins down, competition between suppliers worldwide fierce, and alter trade patterns.¹⁷

Higher volume markets are expected for some plastics, such as ABS, through 1996, as new applications for those plastics take hold around the world.

Consumption of textile chemicals in the United States is expected to slow as growth in the U.S. textile industry slows over the next 5 years, according to Hochberg & Co., New Jersey-based

marketing consultants. Textile fiber use is expected to grow a modest 2% per year to 15.3 billion pounds (lb) in 1996, up from 13.8 billion lb in 1991. However, textile fiber processors used 3.6 billion lb of textile-related chemicals in 1991 and are expected to consume 3.9 billion lb of textile chemicals in 1996 (a growth rate of less than 2% per year). Textile-related chemicals include chemicals associated with dyeing and finishings, such as bleaching agents, soil and water repellents, and backcoating resins. One reason for the slower growth in textile chemical use is a decrease in the use of polymers to bind nonwoven textiles in favor of thermal bonding techniques.¹⁸

PLASTICS

The U.S. economic recession and war in the Persian Gulf put downward pressures on most domestic markets for plastic resins, resin prices, and planned company projects during 1991.

Plastic resin production in the United States rose overall by 3% in 1991, to 22.0 million tons. This growth resulted largely from increased foreign demand for certain thermoplastic resins. By exporting large volumes of thermoplastic resins, many U.S. resin suppliers were able to maintain a level of profitability in spite of depressed economic conditions at home. The surge in export activity caused U.S. resin exports to reach record levels for the year.

Plastic resins sales fell overall by 1.1% to 27.5 million tons in 1991, compared with 27.8 million tons in 1990. Sales were strongest for low- and high-density polyethylene, polyvinyl chloride (PVC), and polybutylene terephthalate, polycyclohexylenedimethylene terephthalate, polyethylene terephthalate (PBT/PCT/PET), while sales were weakest for styrene acrylonitrile, phenolics, and urea/melamine.

Despite recessionary pressures, resin suppliers increased spending on research and development activities to create new products and process technologies to maintain a competitive edge at home and in world markets.

The composition of industry continued to change as moves to address environmental concerns, facilitate recycling, and alleviate the landfill crisis took hold.

Background

Early beginnings of the plastics industry can be traced back to natural compounds such as horn and hoof, tortoise shell, bone, ivory, gutta-percha, shellac, and glue. Forming useful items with these and other compounds necessitated the development of extruders, presses, molds, calendars, and so on, that were later used for synthetic materials as they were developed. In 1929, a generic name for the developing industry was selected by a contest. Synthoid was the winner, but it was shunned by the industry in favor of the word "plastic."

Plastic was favored because the word means that the substance can be molded or formed into any shape, as opposed to nonplastic substances that must be cut or chiseled.¹⁹

Significant dates in the development of synthetic polymers start with Alexander Parkes' introduction of the cellulose nitrate, Parkesine, at the Great Exhibition in London, England, in 1862. (Reference to specific products or companies does not imply endorsement by the U.S. Bureau of Mines.) In the United States, John W. Hyatt independently developed a form of cellulose nitrate and the injection molding machine in 1868. A patent for Celluloid was granted to Hyatt and his brother Isaiah in 1870. It was not until 1877 that A. Kekule postulated that natural products are long-chain molecules. E. Fischer finally verified that the structure of cellulose was indeed a macromolecule in 1893. (See table 5.)

Hendrik Baekeland was responsible for the introduction of the first synthetic thermosetting resin in 1909. The phenolic was known as Bakelite. Commercial development of a number of thermoplastics occurred during the 1930's. W. H. Carothers first synthesized nylon 6/6 in 1935, polyurethanes were invented by O. Bayer in 1937, and R. J. Plunkett discovered

the polymerization of tetrafluoroethylene (PTFE) in 1938. PTFE was developed rapidly to the manufacturing stage under a crash program for use in World War II.²⁰ However, it was not until 1950 that PTFE came into wide commercial production under the trade name Teflon.

Production of PVC and formaldehyde laminates (Formica) began in 1940. Fiber-forming polyesters were developed in 1941, as was PET. The 1950's saw the first commercial production of PET as Dacron, development of polypropylene, polycarbonate, high-density-polyethylene (HDPE), and polyphenylene oxide (PPO). During the 1960's, aromatic polyesters were introduced and the first spun fibers or aramid fibers were developed. Polyimides were introduced, and from them, a whole family of polymers emerged. Several new polymers were introduced during the 1970's. Kevlar, an aromatic polyamide (aramid fiber), became available in 1973, and a modification to PET in the late 1970's made it a popular choice for the blow-molding of beverage bottles. Polyetheretherketone (PEEK), first marketed in 1978, is one example of the newer, high-performance, high-cost polymers that have found applications in the aerospace and computer industries, where high cost is less of a consideration.

The 1980's have seen the introduction of a new melt-processible liquid crystal polymer known as Xydar (Dartco Manufacturing Co., 1984) and the development of new technologies for alloying and blending old polymers to meet specific engineering criteria. Recent developments and trends suggest that many of the "new" polymers will result from future research efforts into the areas of processing and fabrication technologies rather than into the discovery of additional "new" polymers.

As can be seen from table 5, there is often a significant time lag from discovery of a polymer to commercial production of a product. The 12-year lag from discovery in 1938 to wide-scale commercial production of Teflon (PTFE) in 1950, for example, brings up a very important point in the historic

development of the polymers industry. Discovering a new polymer does not necessarily lead to its development or commercialization.

Although the science of polymerization has come a long way in defining how molecules can be engineered to meet specific criteria, development of new polymers into commercially acceptable products can be a lengthy process. Aside from finding new uses for a new polymer, there are patents to consider, processes to be worked out for the large-scale manufacture of the polymer, and cost-effective fabrication methods to be developed. In addition, safety factors and standards have to be met, and in some cases, licenses may need to be issued (such as the Federal Drug Administration's approval for medical uses) before a new product can be introduced into the market. The whole process involves a number of disciplines working together and can take years, even decades, to accomplish. It also costs large sums of money, and that limits the number of participants interested in actively developing new polymers.

Definitions, Grades, and Specifications.—Polymers can be classified according to the structural shape of the polymer molecules. They can be either linear, branched, or cross-linked. Linear polymers have repeating units linked together in a continuous length. When branches protrude from the main polymer chain at irregular intervals, the polymer is termed a branched polymer. Both linear and branched polymers are thermoplastics. They can be softened and hardened by heating and cooling. Fabricating processes like injection molding, casting, and blowing take advantage of this feature to shape thermoplastic resins. The rigidity of thermoplastic resins at low temperatures is attributed to the existence of secondary bond forces between the polymer chains. These bonds lose strength or are destroyed at higher temperatures, thereby causing fluidity of the resin.

Polymers used as textile fibers are linear. However, they must be of high

molecular weight and have a permanent orientation of the molecules parallel to the fiber axis. The chain orientation necessary to develop sufficient strength by crystallization is achieved in the melt during spinning and then by a process known as cold drawing, in which the initially formed filaments are drawn (stretched and further oriented) at a temperature above the glass transition temperature, T_g . (T_g is the temperature at which sufficient energy is available to the molecular segments to cause them to begin to rotate and materials become soft and rubbery.)

Elastomeric materials, like thermoplastic resins and fibers, are essentially linear polymers. Certain distinctive features in their molecular structures make them rubbery. Because their T_g 's are below room temperature, they can be stretched to twice their original length and then can return essentially to their original shape when tension is relaxed.

Polymers or resins that are transformed into a cross-linked product, and thus take on a "set" on heating, are said to be thermosets. Cold flow between molecules can be prevented by cross-links between polymer chains. The structure of polymer chains present in the cross-linked polymers is similar to the wire structure in a bedspring, so chain mobility, which permits one chain to slip by another (cold flow), is prevented. Natural rubber, for example, is a sticky product with no cross linking, and its polymer chains undergo unrestricted slippage. The product has limited use. However, when natural rubber is heated with sulfur, cross linking takes place. Cross linking by sulfur at about 5% of the possible sites gives rubber enough mechanical stability to be used in automobile tires but still enables it to retain flexibility. Introducing more sulfur introduces more cross-links and makes rubber inflexible and hard.

Cross linking is an important process in polymer technology. A high degree of cross linking gives rise to three-dimensional or space network polymers in which all polymer chains are linked to form one giant molecule. Thus, instead

of being composed of discrete molecules, a piece of highly cross-linked polymer constitutes just one molecule. At high degrees of cross linking, polymers acquire rigidity, dimensional stability, and resistance to heat and chemicals. Because of their network structure, such polymers cannot be dissolved in solvents and cannot be softened by heat. Strong heating only causes decomposition. Quite commonly, these materials are prepared, by intent, in only partially polymerized states (prepolymers), so that they may be deformed in the heated mold and then hardened by curing (cross linking).

Polymers generally fall into three major categories: commodity, engineering, and high-performance materials, based on price, volume, and usage of the product.

Commodity materials are the high-volume, low-cost materials that are easily processible. Examples include PVC, low-density polyethylene (LDPE), HDPE, and polypropylene (PP). Some classifiers place ABS in the commodity grouping, but it also finds usage in engineering applications.

Included in the engineering group are polyamides (nylons), polyacetals, polycarbonates (PC), modified PPO, PET, and PBT. These materials are the intermediate grouping in terms of production volume, material costs, and processibility. Engineering polymers have inherent characteristics that make them suitable in areas replacing metals or glass-ceramics. Properties of engineering polymers include good heat resistance, strength, durability, resistance to chemicals and weathering, and good electrical properties (either conductive or insulating).

High-performance materials include polymeric resins and reinforced resins and composites used in more specialized or demanding environments. These materials have a very low production volume relative to the other polymers and a high to very high price, with prices in the hundreds or even thousands of dollars per pound. The polymerization process for high-performance materials is complex, and fabrication is difficult because of their high melting point or

even lack of a true melting point. These materials have exceptional resistance to heat, hostile environments, and chemicals; outstanding strength; and good optical, lubricity, and electrical properties. Polymers included in this classification are polyphenylene sulfide (PPS), polysulfones, polyether-imides (PEI), polyamide-imide (PAI), polyimides, PEEK, fluoroplastics, liquid crystal polymers (LCP), and the aromatic polyamides, polyesters, and copolymers.

Products for Trade and Industry.—Resin suppliers, compounders, and processors, among others in industry, race to create new products or applications to better, if not maintain, their competitive edge in world markets.

Badische Aniline Soda Fabriken (BASF), for example, has plastics applications centers in Europe, North America, and East Asia. In 1992, BASF should be in the final phase of its startup of its new Ultramid nylon 6 resins. Last year BASF increased its domestic Ultraform acetal resins capacity, and, in Europe, Ultrason E polyether sulfone capacity was expanded to meet global market demands. Werner Praetorius, group vice president, has stated, "The fact that we are guided by global forces, supports our continued capital investments."²¹

Thermoplastic elastomers (TPE) have been improved in vapor barrier qualities by Advanced Elastomer Systems, a joint project of Monsanto Chemical Co. and Exxon Chemical Co. The first application for the improved TPE is in blood vial stoppers, which take advantage of the improved water and air vapor barrier qualities. Other medical and general uses are on the horizon.

Akzo Engineering Plastics produced a reduced moisture sensitive polyamide alloy in 1991 by the use of mineral and glass-mineral filled formulations. Other developments have included higher glass loadings in Fiberstran, a long fiber-reinforced thermoplastic, which will enable more metal replacement potential, a nonhalogenated polypropylene with higher modulus, tensile strength, and

flexural strength than halogenated fire retardant polypropylene, and a new Plaslube PL group of thermoplastics that make use of polymeric lubricants like PTFE.

Amoco Performance Products commercialized third generation liquid crystal polymers in 1991 with a range in both heat resistance [up to 671° F heat distortion temperature (HDT)] and cost. Also introduced were Radel polyphenylsulfone (PES) injection molding grades for aircraft interiors, and a PES resin is being tested for aircraft sheet. Twelve grades of Amodel polyphthalamide with melt temperatures of 590° F and HDT of 545° F have allowed the gap to be bridged between traditional engineering thermoplastics and higher cost materials such as liquid crystal polymers. Twenty percent to 30% carbon filler in the polyphthalamide grades are being used to increase friction wear for bearings, and high stiffness is obtained in a cost effective manner with mineral/glass filler.

Arco Chemical Co. introduced three grades of Dylark FG high heat styrene copolymers for microwaveable food packaging in impact, clear, and foam options.

Color stability in thermoplastic olefins (TPO) was increased by D&S Plastics International in both paintability and molded-in color. This combines well with the new 700 TPO's featuring higher stiffness for use in automotive cladding and vertical body panels.

In 1991, Dow Plastics introduced a new hydrochlorofluorocarbon compatible polyurethane foam/styrenic alloy liner system for refrigerators and freezers. This new liner system does not require a coextruded or laminated barrier to prevent the blowing agent from attacking the liner. New grades of high gloss acrylonitrile butadiene styrene and polystyrene are finding applications in small appliance housings and microfloppy diskettes, respectively. Also introduced in 1991 was Derakane 441-400 vinyl ester resin with less than 35% styrene, which helps reduce vapor emissions.

E.I. du Pont de Nemours & Co. introduced a toughened nylon resin with

low mold deposits and a halogen-free nylon for wire and cable coatings. The Delrin line of acetal resins added improved series with better weld line strength and melt stability.

Eastman Chemical Co.'s series of Tenite resins, low-temperature extrusion coating specialty polyethylenes, were marketed so that coextrusion could be accomplished at temperatures 25% to 30% below normal, allowing bonding with heat-sensitive resins such as ethylene-vinyl acetate and ethylene-vinyl alcohol.

Exxon Chemical Co. produced a clarified polypropylene with high moisture barrier, clarity, and impact resistance by increasing the level of molecular linearity in the polypropylene resins. Also, a polypropylene film was developed that offers low-temperature heat seal for bag applications and medical tubing.

GE Plastics introduced a new line of polycarbonate copolymers, Lexan SP resins, that have extended the flow and impact properties. Lexan PK2870 is being molded into the first gallon-size reusable polycarbonate bottle, Lexan F8000 sheet has met regulations for use in aircraft interiors, and Lexan FR700 was introduced as a polycarbonate film for electrical barrier insulation. GE also introduced a paintable thermoplastic elastomer for automotive exterior uses, such as soft bumper fascias, and an ABS resin with higher heat properties for automotive interiors.

Himont Corp. introduced a clear, radiation-resistant PP for injection molding medical products and labware and a superclear grade for housewares. Competitiveness with ABS has been increased by raising the flexural modulus, and low modulus grades have been introduced that make PP suitable for calendaring so that liner material can be produced to line ponds and landfills. In the Far East, foam processing of PP was achieved, allowing the production of PP foam pipe insulation and food trays.

Hoechst Celanese introduced a 40% glass filled polyphenylsulfone resin designed for thin wall, surface-mount electronic connectors with increased heat

deflection temperature, faster cycle times, and better flowability.

LNP Engineering Plastics introduced new formulations of long fiber reinforced plastics in its Vertron line.

Mobil Chemical Co. has introduced a new high impact polystyrene (PS) injection molding resin with faster cycle times. Applications in durable goods, appliance parts, housewares, and toys are being considered.

Monsanto has increased the weatherability, ultra-violet resistance, and color stability in its acrylonitrile-styrene-acrylic (ASA) and acrylonitrile-ethylene propylene diene monomer-styrene (AES) resins. The heat resistance and moldability are comparable to that of ABS. Uses are in custom extrusions for truck caps, pool steps and spas, recreational vehicles, boats, and personal watercraft.

Novacor Chemical Inc.'s Plastics division introduced a new series of TPE, the Sarlink 3000 Series, and a new TPE in its 2000 series. The 3000 series was developed as substitutes for ethylene propylene diene monomer and neoprene rubber. Hardness is available in a variable range for both the 2000 and 3000 series with the 2000 series covering the lower end of the range. Applications are in blood vial stoppers, paper rollers, and copier belts. Four new injection molding grades of compounded methyl methacrylate, styrene, and butadiene were also introduced. Advantages include improved alcohol resistance and stability of color/property retention after gamma sterilization, which should enable these new compounded plastics to find uses in the medical field.

Rogers Corp. phenolic composites are currently being used in automotive power train components. Improvements in properties have been obtained by new compounding technology and resin toughening.

Industry Structure.—Most of the domestically produced resins are produced by a relatively small number of large companies. For example, PE, the largest resin category, has 18 producers, but the top four companies have more

than 50% of nameplate capacity. ABS has only three domestic producers. PVC has 12 domestic producers, but the top 4 account for 66% of capacity. PP has 14 domestic producers, and the top 4 account for 59% of total capacity. PS has 14 producers, 63% from the top 4. Table 6 lists the domestic production capacity of PE, PP, PS, and PVC, along with the capacity utilization rates for each of the past 5 years. (See table 6.)

A survey conducted by Plastics News in 1991 profiled the custom injection molding industry, the most widely used plastics fabrication technology.²² (The extrusion process accounts for more resin usage, but has far fewer facilities.) As of September 9, the number of completed surveys returned totaled 215 from the more than 1,000 companies that were asked to participate. The findings reported here are based on those surveys. The survey identified the top 100 injection molders, ranked by sales of custom injection molded products in their most recent full fiscal year in North America. Together, these companies had sales of more than \$5.13 billion in injection molded resin products and processed more than 1.5 billion pounds of resins.

The top 5, and 14 of the top 20, injection molders were engaged exclusively or in large part in supplying the automotive industry. All of them had more than 1 plant and injection molding-related employment levels between 500 and 2,900 persons. Most of the businesses supplied plastic products to more than 1 industry, but 18 of the 100 were engaged in a single industry; 12 to automotive, 3 to packaging, and 1 each to aerospace and other transportation, housewares/consumer product, and medical/pharmaceutical/health care.

Table 7 gives information on the number of U.S. plants engaged in fabrication of plastics using one or more primary processes. This information indicates that injection molding is the most prevalent method of fabrication, followed by extrusion. As shown by this and figure 6, the structure of the plastics processing sector is such that more than 50% of fabrication is performed by

captive plants. (See table 7 and figure 4.)

When the plastics industry is looked at from a perspective of how much resin is processed using each of the major technologies, a somewhat different pattern emerges. Even though injection molding accounts for the largest number of operations, table 8 shows that extrusion is the dominant technology in terms of the amount of resin processed. In 1991, more than 37% of all resins were extruded, about four times the amount processed with injection molding machinery. Blow molding, the third largest technology used, accounted for more than 7% of total resins. A principal reason for this division is that extrusion machinery can create simple shapes, such as pipes and profiles, at a very high throughput rate and very low costs. Injection molding is a very versatile processing technique, but is not a continuous process. Parts can be molded singly or even in multiple numbers relatively cheaply, but each cycle requires a mold fill, cooling, and ejection of the part before the next cycle can begin. (See table 8.)

Developments in capacity expansions worldwide show that during the past 5 years, capacity of PE in North America increased by 9 billion pounds, a 42% increase in nameplate capacity. In 1991, U.S. domestic demand for PE fell for the first time in 10 years. Despite this decline, new PE capacity, amounting to 2.1 billion pounds, is planned for the United States in late 1992 and early 1993 by Dow, Phillips, Eastman, and two new companies in the PE market, Himont Inc. and Formosa Plastics USA. Dow Plastics forecasts a 3% to 4% rise in domestic demand for 1992.²³ Montecatini of Italy, the parent company of Himont, expects to supply PE earlier than originally anticipated as a result of its plans to retrofit a new PE unit to an existing PP plant in Bayport, TX.

In 1988, PP capacity in the United States was 6.9 billion pounds; it now stands at 9.4 billion pounds—an increase of 36% in nameplate capacity. This increase occurred despite the closure of old-technology process units such as those

of Eastman Chemical, which recently brought up a new Unipol PP unit. Amoco has scheduled a 300-million-pound unit to be on-line in the second quarter of 1992, and Formosa Plastics has a scheduled startup of a 450-million-pound unit at Point Comfort, TX, late in 1992. Last October, a 260-million-pound PP plant employing the Unipol process was brought on-line by Epsilon Products at Marcus Hook, PA.

BF Goodrich (BFG) has plans to shut down more than one-half billion pounds of PVC capacity by 1993 to concentrate on producing lower volume, more profitable specialty grades of resins. The BFG marketing manager predicts that the North American PVC industry will require four new plants to meet the expected annual growth of 3.5%.²⁴ Present needs are met by four primary producers, BFG, Oxychem, Formosa, and Shintech, which account for more than 70% of PVC produced. BFG continues to concentrate on value-added compounds like its new high-stiffness, rigid vinyl extrusion compounds that offer a lower coefficient of linear expansion and higher heat deflection. Oxychem on the other hand tends to deal in large-volume markets, so it concentrates on increasing its chlorine and ethylene production rates. Formosa Plastics is attempting to become the most fully integrated PVC producer in North America so that it does both feedstock production and PVC products. Formosa Plastics is already the largest U.S. PVC pipe producer. Shintech is producing for large-volume markets and exports, which enables it to take advantage of its large reactor technology.

PS production in 1991 was at 75% of nameplate capacity; for this reason there are no plans to increase capacity in the future. Shutdowns of two plants in 1991 by Dow Chemical (200 million lb/yr) at Midland, MI, and Novacor (70 million lb/yr) were balanced by the startup of one new plant, Mobil (120 lb/yr), and a restart of a previously mothballed plant by Deltech (145 million lb/yr) at Willow Springs, IL.

North American production capacity for ABS is currently being boosted to 2

billion pounds per year. Monsanto plans to bring on-line an 80-million-lb/yr plant at Cincinnati, OH, in the third quarter. GE Plastics has plans for a 150-million-lb/yr expansion in 1992 at Ottawa, IL and Bay Saint Louis, MS, and Dow Plastics will start up a new plant producing 60 million lb/yr in Midland, MI. The domestic demand in 1991 was only 1.2 million lb/yr, but the planned expansions in capacity are not expected to create an oversupply of ABS.

There are plans by several of the key producers in the PET industry to expand capacity to keep up with the rising demand. Chief among these producers worldwide is Germany's Hoechst A.G., which has plans to expand capacity by 480 million lb/yr through its U.S. division, Hoechst Celanese, and Mexican division, Celanese Mexicana. This expansion will take place in two phases. The first phase will involve debottlenecking and restarting idle capacity at plants at Greer and Spartanburg, SC, for an increase of 130 million lb/yr in 1992 along with a new solid-state unit to be built in 1993 at Quetaro, Mexico. The second phase will include two new 140-lb/yr plants to be opened at Spartanburg, SC, in 1994 and in 1995. Shell Chemical's Italian branch plans a joint-venture plant producing 130 million lb/yr with Mossi and Ghisolfi at Frosinone, Italy. Startup is scheduled for the middle of 1992. Eastman, the largest producer in the United States, has plans for 340 million lb/yr in the next 2 years. This will be achieved with a debottlenecking in 1992 at a plant in Columbia, SC, boosting production by 100 million lb/yr and by two new plants in the United Kingdom adding 240 million lb/yr. Imperial Chemical Industries has plans for a 113-million-lb/yr expansion in Europe and a production increase of 39 million lb/yr in the United States for 1992.

In the United States, Reichold Chemicals, the largest domestic supplier of TPO and a subsidiary of Dainippon Ink and Chemical of Japan, is attempting to obtain a 75% stake in Alpha Chemicals, which will make their

collective capacity 825 million lb/yr, the world's largest.

In 1992, Du Pont is bringing on-line a 30-million-lb/yr compounding plant in Parkersburg, WV, for engineering resins. Peter Rigby, senior development manager, says that this plant will allow rapid scaleup of materials, custom coloring, and competitive turnaround times. This endeavor by Du Pont is indicative of a trend whereby engineering resin producers are attempting to develop specialty resin grades that closely match the design requirements of the products.

Technology.—Processing.—Products with good performance characteristics can often be produced at low cost with flexible, high-volume, automated methods such as extrusion, blow molding, and injection molding. Those resins that are best suited to these high-volume methods are likely to continue to grow in importance.

Fabrication processes for the thermoplastic and thermoset classifications of plastics take advantage of the chemical differences between the two, although progress in technology has lessened the effective, if not chemical, distinction between them. Thermoplastic resins may be processed hot, cooled, and then reheated and reprocessed, while thermosetting resins cross link in processing and cannot be reheated and used again.

Common thermoplastics include ABS, PVC, SAN, acetals, acrylics, cellulose, PE, PP, PS, polycarbonates, polyesters, nylons, and fluoropolymers. The most important processing techniques for thermoplastics are injection molding, extrusion, and blow molding. Other processes include thermoforming, casting, rotational molding, calendaring, and spinning.

The common thermoset resins include phenolics, ureas, melamines, epoxies, alkyds, unsaturated polyesters, silicones, and urethanes. The most common processing methods are compression and transfer molding, but thermosetting resins are also processed using reaction injection molding (RIM) techniques, pultrusion, casting, and foaming processes.

The machinery used to process plastics comes from suppliers in a large number of countries. In Western Europe, Germany, Italy, and the United Kingdom have large machinery sectors and export a large percentage of what they produce. In Asia, Japan is by far the leading producer of plastics processing machinery. In North America, the United States produces the largest number of machines, but Canada has a surprisingly robust machinery industry. Table 9 shows the number of plastic fabrication machines sold into the U.S. market. (See table 9.)

Domestic manufacturers of plastics processing equipment saw total shipments of U.S.-made injection molding machines drop 9% in 1991, to 1,611 units from 1,770 units in 1990. Shipments in all nine clamp force categories as reported by the Society of the Plastics Industry, Inc. contributed to the decline, except those with clamping forces of 0 to 99 tons and 750 to 1,199 tons. The clamp force category of 0 to 99 tons accounted for the largest number of machine shipments in 1991 with 390 units, up from 373 units in 1990. Shipments of machines with clamping forces of 750 to 1,199 tons rose to 70 units in 1991 from 66 units in 1990. Imports of injection molding machines fell 4.1% to 2,366 units. In terms of market share, U.S.-made injection molding machines, with 41%, and imported injection molding machines, with 59%, accounted for approximately the same percentages of the U.S. market in 1991 as those of 1 year ago.

Total shipments of U.S.-made single-screw extrusion machines dropped 5.5% to 952 units in 1991 from 1,007 units in 1990. Machine shipments fell in five of seven categories based on screw diameter and rose in the two other categories. The sharpest drop in shipments occurred in the less than 2-inch category, while the largest gain was in the 7.5-inch and larger category. The 2.5-inch but less than 3-inch category accounted for the largest number of shipments in 1991 with 318 units, down from 321 units in 1990. Despite the decline in total domestic shipments, U.S.-made extrusion machines

captured a markedly higher percentage share of the domestic market, rising to 72% in 1991 from 57% in 1990. Imports of extrusion machines fell 51.7% to 374 units in 1991 and accounted for 28% of the U.S. market.

Recycling.—The U.S. plastics industry continued to make progress during the year toward meeting its goal of recycling 25% of the country's plastic bottles and rigid containers in 1995, despite the economic recession, low virgin resin prices, and an oversupply of recyclable materials. According to the Partnership for Plastic Progress (PPP), a program of the Society of the Plastics Industry, Inc., plastic bottles and containers were recycled at an 11% rate in the United States in 1991; an increase of 4% from that of a year ago. The recycling rate for PET soft-drink bottles rose 6% in 1991 to 36%, while the rate for all bottles climbed to 14%.

Concerns about toxins in postconsumer plastics contaminating the beverage have kept used beverage bottles from being recycled into new ones. But, major soda producers have entered the market recently with bottles made from postconsumer PET broken down chemically and then regenerated into PET.²⁵ On March 12, 1991, Coca-Cola Co. began testing its 2-liter PET soda bottle containing 25% recycled resin.²⁶ The Food and Drug Administration removed its proscription against the use of recycled resins because the PET resins regenerated by Hoechst Celanese were chemically depolymerized and then repolymerized in a methanolysis reaction process. Pepsi-Cola Co. introduced its recycled-content 2-liter bottle in late 1991 with recycled resins by Eastman Chemical Co., which also uses a methanolysis reaction process. The Pepsi-Cola Co. had originally planned to test-market bottles made from Goodyear's resin produced in a glycolysis process during the summer, but is now expected to introduce these bottles in early 1992.²⁷

Hoechst Celanese is expected to continue to supply the Coca-Cola Co. with its repolymerized PET for inclusion in its beverage bottles, and Goodyear is

expected to supply Pepsi-Cola Co. with its Repete resins. Eastman is expected to supply 50 million lb/yr of its 25% repolymerized-75% virgin blend to molders in 1992.

There is also an uptrend occurring to recover the hydrocarbons from recycled plastics called "tertiary recycling" by more companies as landfill space continue to dwindle. In tertiary recycling, plastics are ground and remelted into fillers and fibers, or minor constituents in resin blends, or processed into fuels. Companies such as Eastman Chemical (Rochester, NY), Du Pont Co. (Wilmington, DE), Goodyear Tire and Rubber Co. (Akron, OH), Sanwa Kako Co. (Kyoto, Japan), Hoechst AG (Frankfurt, Germany), BASF AG (Ludwigshafen, Germany), ICI plc (London, United Kingdom), and Veba AG (Dusseldorf, Germany) are chemically unzipping or thermally cracking polymer chains to recover monomers to make resins that are indistinguishable from virgin material. The remaining hydrocarbons fractions are either refined as petrochemical feedstocks or sold as fuel or fuel additives.²⁸

Tertiary recycling can be accomplished by either a chemical or thermal process, depending on the polymer considered. Glycolysis, methanolysis, and hydrolysis are all chemical ways used to unzip condensation polymers such as polyester, nylon, and polyurethanes. Thermal processes must be used to break down addition polymers such as vinyls, acrylics, fluoroplastics, and polyolefins. Refineries have been experimenting with thermal processes because pyrolysis units are already part of their infrastructure. Obstacles to this process, at present, are contaminants such as chlorine and nitrogen in the plastics waste and the need to turn the plastics waste into a liquid stream. Amoco and Chevron are using bench- and pilot-scale tests to assess the feasibility of several options such as small-scale pyrolysis; dissolving plastics into other refinery feedstocks; or converting the solid waste into a slurry that can be pumped. Two companies producing gasoline fuels from recycled plastic waste are Central Fine Pack and

Fuji Recycle. Central Fine Pack of Fort Wayne, IN, a subsidiary of Chuo Kagaku Ltd. of Kohnosu City, Japan, produces a diesel oil from commingled plastics in a steady stream process. Since 1988, Fuji Recycle Industry K.K. of Aioi, Japan, has produced 500 metric tons per year of gasoline from polyolefin plastic waste.

Europe and Japan now lead the United States in commercializing applications for plastic scrap. In Europe, new packaging applications have provided the stimulus for developing tertiary recycling processes. A European Community directive setting 90% collection and 60% recycling quotas on packaging waste is expected to be presented by yearend 1992, and if enacted by the European Parliament, it will be phased in over 10 years. Meanwhile, several countries have already set their own goals for plastics recycling. Italy, for example, has set a recycling quota of 40% for plastics containers. The Netherlands has set a goal to recycle 35% of all plastics and to recover energy by incineration of another 45% by the year 2000. The most aggressive regulations were enacted in Germany, where, by 1995, 64% of all product packaging must be recycled.

Substitutes.—Polymeric materials are being substituted for glass, ceramics, metals, and paper in many applications. As polymers with improved physical properties are developed, substitution for other polymers also occurs. Everything from microwave food packaging, with its multiple layers with barrier properties, to housewares, to sporting goods, to automobile bumpers, to satellites and aircraft are now made with polymeric materials. Some areas of substitution encourage new product development by the polymer users such as food packaging. Others improve product durability and provide weight savings and/or cost savings.

One new application of PVC is for marine panels such as ShoreGuard-brand extruded marine panels from Universal Bulkhead, using BFG's Geon vinyl. The new panels are stronger than wood in most cases and more durable than steel, according to BFG. Also, the products

resist exposure to water, sun, and temperature cycling, and their light weight simplifies installation along waterways, ponds, and golf courses.²⁹

In another application, PCT is being used instead of metal for some wheelchair components. The moldability of PCT helps in parts consolidation and cost reduction.³⁰

Economic Factors.—U.S. resin prices were affected by the economic recession, abundant resin inventories, and events in the Persian Gulf during the year. An interplay of these factors caused resin prices, in response, to rise and fall and, at times, rise again. Prices for the commodity-grade resins were markedly up, as were prices of crude oil, at the start of the year (table 10). PS, for example, started the year with large-volume prices from 57 to 59 cents; injection-grade HDPE, from 45 to 48 cents per pound; and PP from 43 to 47 cents per pound. A general easing in resin prices toward midyear lead to lower prices in July for those resins. The availability of adequate feedstocks for resin production, ample resin stocks, and weak resin demand were, in large part, the key elements to spur on competitive price cutting. By December, however, prices for most virgin resins had climbed to slightly higher levels. (See table 10.)

Prices for recycled plastics seemed to be less affected by the soft market conditions of midyear, as they remained unchanged or increased only slightly in July, before falling to lower prices in December.

Annual Review

Legislation and Government Programs.—One regulatory issue in 1991 surrounded a heated debate concerning the use of the words "recycled" and "recyclable" on plastic products. Federal agencies were lobbied for a national solution, State governments made proposals for a national solution, and third party organizations such as Green Cross and Green Seal each made their own suggestions. A group of plastic

manufacturers and retailers lobbied the Federal Trade Commission for standards on the use of the words in a context that would clarify their meanings. Among their suggestions were requirements that labeling should include specific statements as to recycled content in a percentage form and that either recycling centers be made available or the disclaimer "recyclable where facilities exist" be included in the labeling. By the end of the year, the issue had not been resolved; however, it is expected that a solution will be arrived at in 1992.³¹

The "Green Laws" passed in Europe regulating the use of PVC in packaging and disposables are still causing some to predict that future legislation is imminent in the United States. No rulings on this front occurred in the United States at the Federal or State level in 1991.³²

New clean water rules issued by the Environmental Protection Agency (EPA) in 1991 could affect plastic processors where bulk loading of resins occurs. Plastic pellets or other raw materials could find their way into rainwater runoff, leading to a violation of the Clean Water Act.

EPA decided not to include styrene as a probable human carcinogen, and two States, North Carolina and South Carolina, relaxed their air quality standards following the release of a report by the Styrene Information and Research Center on the alleged health risks of styrene exposure.

Also, EPA issued new regulations in 1991 under the 1990 Clean Air Act that tighten standards for the "permit to pollute." Former small operators, defined in the past as operators emitting less than 100 tons/year of a smog-causing pollutant, have found themselves reclassified depending on their location. The new regulations permit varying levels of emissions depending on the local air quality, thus some operators previously considered as small are now classified as major polluters. These new regulations will affect resin manufacturers and manufacturers of the basic petrochemicals involved in plastics.³³

In August, the FDA issued a rule on "Colorants for Polymers" that makes the

following assertions: colorants have been shown to migrate to food from polymers, colorants are food additives, and colorants are subject to the Federal Food, Drug, and Cosmetic Act. This may lead to a requirement for colorant or packaging manufacturers to petition the FDA for clearance of all colorants used in their products.³⁴

Issues.—California enacted a law that makes it illegal to claim a product as "recycled," "recyclable," "ozone-friendly," or "biodegradable" without meeting criteria laid down by the U.S. Federal Trade Commission (FTC). "Recycled" is defined by the FTC as meaning an item that contains a minimum of 10% by weight reclaimed postconsumer material and can be recycled in every country having a population of at least 300,000.³⁵

In March 1991, the EPA and Occupational Safety and Health Administration (OSHA) announced a plan to implement cooperative efforts between the two agencies, including joint inspections of petrochemical plants, hazard referrals, and training programs. This action was in response to a recent spate of explosions and fires in petrochemical plants, the most recent example of which was the March 12, 1991, fire at Union Carbide's Seadrift, TX, facility.

In June 1991, the Council for Solid Waste Solutions (CSWS) announced the beginning of a campaign to change the public's perception of plastics in the environment. An opinion poll commissioned by the CSWS in 1990 indicated that a majority of Americans, 54%, rated plastics as unfavorable compared with 34% in 1988. Methods to improve collection and sortation technologies for recycling are being considered by industry leaders. Jean Statler, communications vice president at CSWS, believes that the public is most likely to believe that plastics are recyclable when they become involved in a curbside collection program.³⁶

The Society of the Plastics Industry (SPI) launched a campaign, Operation Clean Sweep, to prevent plastic resins

pellets from finding their way into the oceans and rivers of the world. New regulations from the EPA dealing with stormwater runoff had added a sense of urgency to the SPI's campaign.

The Council on Plastics and Packaging in the Environment (COPPE) commissioned a study on solid waste issues from which it has drawn several conclusions about public misperceptions concerning the solid waste problem. Americans are said to assume that trash disposal is the most pressing environmental issue, curbside collection and recycling of trash is the primary solution to the solid waste problem, and recycling rates of 25% to 50% are entirely feasible. COPPE believes these perceptions are false and that overselling recycling puts source reduction on hold. Furthermore, COPPE thinks source reduction efforts that have occurred in plastics packaging through downgaging and redesign should be publicized more often.³⁷

The Center for Plastics Recycling at Rutgers (CPRR) University is working on a bar code label for plastics bottles to allow sorting of plastics by polymer type, additive and filler content, color, brand name, and other data. The motive for this code being initiated is that the CPRR feels that recycling's success depends on the increased use of automated computer-controlled sortation.

The World Wildlife Fund & Conservation Society, Washington, DC, was given a Federal grant in 1991 to develop guidelines for source reduction policies in solid waste management. Key strategies that have emerged from this study include: product life extension, product life assessments or lifecycle analyses, and design for disassembly. John Kusz, chairman of the environmental affairs committee of the Industrial Designers Society of America, said that incentives can be implemented to combine longer product life with healthy profits. He cited the imposition of recovery fees on durable products as a possibility. The advantages to this fee would be that a collection system would be encouraged because consumers would wish to recover their fees and

manufacturers would be encouraged to extend product life because they would want to postpone the payment of fees. Lifecycle analyses are valuable tools in analyzing the impact of a product on society, but there needs to be established a common methodology for performing these studies so that the information is useful in comparing products. The Society of Environmental Toxicology and Chemistry, Washington, DC, met in February 1991 to discuss the role of lifecycle analyses and their methodologies.

Whirlpool Corp. has issued a mandate that its service units collect chlorofluorocarbon-12 (CFC) in PE bags for recycling to prevent the damaging effects CFC has on the ozone layer.

BFG, Cleveland, OH, started a pioneer program to reclaim the commingled LDPE and PVC fluff from shredded cable jacketing. The impetus for this program is the expectation that under new EPA guidelines this fluff will be classified as hazardous waste leading to much higher disposal costs.

Production.—U.S. plastics production in 1991 rose by 3% overall largely due to increased production of several major thermoplastics, namely, thermoplastic polyester, HDPE, and LDPE (table 11). Taken separately, thermoplastic polyester production increased 12% in 1991, to 1.0 million tons; HDPE production, 11% to 4.2 million tons; and LDPE production, 4% to 5.3 million tons. Epoxy, a thermoset, also contributed to the overall production increase, rising 6% in 1991. Production growth for those resins resulted from strong demand in U.S. export markets. Production of most other resins declined during the year. (See table 11.)

Polyurethane (PUR), the largest volume thermosetting resin, experienced a 9% decline in domestic production in 1991. Flexible PUR foam use declined 12% in 1991 especially in automotive rigids. An environmental concern for PUR is the use of CFC's as a blowing agent. The use of CFC's as a blowing agent declined almost 50% by 1991, and this process is predicted to continue until

there is complete elimination of CFC's use by 1994.³⁸

Phenolics production declined 10% in 1991 from that of a year ago. The United States trails in applications of phenolics to construction and transportation where properties such as low flame and smoke make them useful for safety. Currently European technology is being imported in the form of sheet molding compounds and liquid resins for filament winding, layup, sprayup, and resin transfer molding. Thermosetting polyester or unsaturated polyester experienced a 12% decline in domestic production as a result of the recession and environmental concerns of using nonrecyclable plastics. New applications offering higher heat-distortion temperatures and increased flame resistance have led to an increased use of unsaturated polyesters in the European markets.³⁹

Consumption and Uses.—In 1991, economic recession and environmental concerns continued to place downward pressure on most activities in the U.S. plastics industry, resulting in an overall decrease of approximately 1% in plastics consumption.

Among the large-volume resins listed in table 12, LDPE consumption decreased to 4.7 million tons in 1991, slightly more than 4% below the 1990 level. The biggest declines in LDPE use during the year occurred in the extruded pipe market and extruded film markets for both packaging and nonpackaging purposes. HDPE consumption, which decreased only slightly, stood at 3.9 million tons.

PVC consumption declined 6% in 1991, to 3.5 million tons. The decrease is due, in large part, to weak domestic demand in the building and construction market, a major consumer of PVC pipe, tubing, and siding. In a good year PVC pipe and fittings account for about 60% of the total PVC market. Environmental concerns targeting PVC use in bottles also curbed domestic demand during the year. However, concerns about incineration of PVC appears to be diminishing.⁴⁰ (See table 12.)

Polystyrene consumption in 1991 fell about 6%, a rate that was lower than expected, because of the recession and environmental concerns prompting a decrease in PS packaging and disposables. Principal markets for PS are packaging, disposables, and low-cost consumer goods.

Markets and Prices.—Prices of large-volume resins hit lows not seen in years in the third quarter of 1991 before rebounding in the fourth quarter.⁴¹ At the end of the fourth quarter, however, prices of basic-grade thermoplastics, having bounced back, were still down 17% to 30% from fourth quarter 1990 levels.

The onset of winter and a concurrent rise in crude oil prices spawned increases in ethylene, propylene, and benzene prices during fourth quarter 1991. Those increases, in turn, led to higher prices for the plastic resins derived from those basic petrochemicals. Attempts to raise prices for a second time were later made by some suppliers for select resins. It was expected, however, that a wave of new capacity for basic petrochemical production brought on-line during the year would cause resin prices to fall, but the closings of a number of old-technology plants prevented that effect from being as influential.

U.S. plastic resin sales totaled 27.5 million tons in 1991, or 45% of world sales (table 13). Compared with that of last year, this represents a decrease of 1.1% in domestic sales. Among the major large-volume plastics, HDPE, with 15.2% of sales, ranked first in volume sold during the year, followed by PVC, with 15.1%; and PP, with 13.5%. The fastest growing markets in 1991, in descending order, were the category combining the engineering resins PBT, PCT, and PET; HDPE; and LDPE. (See table 13.)

Foreign Trade.—The U.S. plastics industry became increasingly dependent on foreign markets to help offset losses incurred due to weak resin demand across most domestic markets—making 1991 an extraordinary trade year.

Fewer volumes of the imported resins listed in table 14 were needed to satisfy domestic demand in 1991, compared with those of a year ago. LDPE imports, at 0.38 million tons, exceeded the volume of any other resin imported during the year. HDPE imports, at 0.16 million tons, ranked second in resin volume imported. The least imported resin was PP, with imports amounting to 0.02 million tons. Resin imports posting the biggest volume declines were PS, down 35%; PVC, down 34%; and LDPE, down 19%. (See table 14.)

Exports of the resins listed in table 14 increased significantly in 1991, except PP, which decreased. For many of the resins, the exported volume hit record highs. LDPE, with exports at 0.82 million tons, was the principal resin exported; followed by PP, with exports at 0.71 million tons. The least exported resin was ABS, with exports amounting to 0.09 million tons. Resin exports posting the biggest gains were PVC, up 59%; LDPE, up 55%; and HDPE, up 43%. When net exports are considered, LDPE, followed by HDPE and PS, posted the biggest, and yet spectacular, gains.

World Review.—As slow economic growth or recession prevailed, most countries exhibited declines in plastic resin sales in 1991 compared with levels of a year ago (table 15.)

The United States, with 45%, accounted for the largest share of world plastic resin sales for the year, followed by Japan, with 16%; the U.S.S.R., with 7%; France, with 6%; and Germany, with 5%. Of those countries, only Japan and France posted overall gains in resin sales for 1991 from the year-earlier levels. In each of those countries, nearly all of the plastic resins listed in table 15 contributed to the overall sales increase, but by comparison, growth in PE sales was stronger. (See table 15.)

Outlook

U.S. supply patterns for both commodity plastics and engineering resins

are changing. The economic recession affected distribution patterns in the United States as domestic demand for commodity resins fell by 3% in 1991. However, U.S. commodity resin exports increased 31% for the year, enabling resin suppliers to recover from the decline in the domestic market. Future increases in U.S. resin exports will depend more on global supply patterns, which are themselves changing. In 1992, U.S. shipments of plastic resins are expected to increase to \$27 billion. But as international competition intensifies, U.S. resin exports are expected to decline in the long term. Imports of U.S. resins are expected to rise with increased global production and a stronger dollar.⁴²

Future PE supply will be affected by increased PE recycling and source reduction efforts. A number of companies established PE recycling plants during the year to better their positions in the market. Some suppliers concentrated their efforts on an alternate PE supply source, while others sought to offer high-quality resins containing more post-consumer reclaim. In addition, the application of high-molecular-weight HDPE bimodals (i.e., a combination of short-chain and long-chain molecules) in PE film and blow molding markets has made more downgaging possible. However, source reductions realized by downgaging may eventually be accompanied by new PE demand as high-molecular-weight HDPE processes find potential new markets owing to their benefits, especially higher environmental stress crack resistance. By the mid-1990's, the impact of these efforts on virgin sales is expected to be sizable. According to conservative estimates, reclaim use is expected to reduce demand growth for virgin resin by 1% per year.⁴³

Domestic PP production should grow about 6% per year in the 1990's, says Bob Bauman, vice president of Chem Systems. However, PP production growth may be further affected once planned PP capacity projects come on-line in 1992. An anticipated 1992 sales recovery for PP will be linked to low prices and the benefits of new polymerization technologies. PP

producers have nearly completed a switch to super-high-activity PP catalysts (Unipol process) that produce a resin with high crystallinity (98% plus). The higher stiffness of these resins has created new demand and helped boost PP sales. The switch to the Unipol process has created a shortage of the old atactic PP that is mainly used in roofing. Two companies, Eastman Chemical and Rexene Corp., have converted old technology reactors to make atactic PP. In addition, Rexene is developing new uses for atactic PP such as a coextrusion tie-layer and as an adhesive in auto carpeting. The use of PP-based copolymers, with 25% to 60% synthetic rubber, is growing in the automobile bumper and fascia markets because of gains in their low-temperature impact and low flexural modulus properties.⁴⁴

Domestic PVC consumption is expected to increase in 1992 to approximately 3%, the same rate as projected for the U.S. Gross National Product. Exports of PVC are expected to continue at a level well over 1 billion pounds. An anticipated upturn in the recession-plagued economy is expected to boost the construction industry and, in turn, lift the strongly tied PVC market—where pipe and fittings account for about 60% of total PVC demand. Environmental concerns about PVC use appear to have leveled off in the United States. These concerns stem from the chlorine and the heavy metal content of PVC. A significant decline in the use of PVC in bottles is not expected in the next year. However, legislation in Europe is limiting the use of PVC in packaging.⁴⁵

Environmental concerns are affecting PS consumption. The perception that plastics are a major cause of the solid waste disposal problem is expected to induce additional cutbacks in PS use, especially in packaging and disposables. PS is mainly used in packaging, disposables, and low-cost consumer goods. Market development efforts by PS suppliers to expand PS use are focused on improving impact strength, surface appearance, and environmental stress crack resistance properties in anticipation of changeovers in extrusion

and injection molding applications. Enhancement of these properties will allow PS to be used in more durable goods such as appliance housings and automobile rigids.⁴⁶

Future growth for ABS appears positive for both environmental and product quality reasons. ABS is recyclable, and its miscibility with other resins, including nylons, PVC, and polycarbonate, has contributed to ABS's utility. Higher heat resistance, glossy surface appearance, and custom coloring are properties that are enabling ABS to compete effectively in the automotive and appliance markets.⁴⁷

SAN consumption is expected to increase next year. New high-clarity versions of SAN introduced in 1991 by Monsanto and Dow are expected to compete effectively with the more expensive resins, including polycarbonate and acrylic, for use in durable goods such as housewares.⁴⁸

Demand for PET is expected to continue to increase in the future because of the resin's high degree of perceived environmental benefits and new or expanded applications created by process innovations and materials substitution. PET is competing in the bottle market with PVC as a result of new resin grades that allow PET to be extrusion blow molded. Formerly, PET bottles were injection molded, and PVC bottles were extrusion blow molded. The resin grades of PET will permit material substitution without capital investment in new processing equipment. Also, downgaging and new coating treatments of PET films have created new markets for PET in the packaging industry.⁴⁹

TPO production is expected to undergo global growth as suppliers and fabricators worldwide expand outside their traditional markets, seek new end use applications, and pursue access to TPO technology that meets end-user's universal product requirements. The unsettling effects of the economic recession or sluggish economies on industry activities in the United States, Europe, and parts of Asia have been key influences to bring about those endeavors. Three major suppliers of TPO formed a consortium in 1992 in

which technology will be shared amongst all three companies, Owens-Corning in the United States, BASF in Germany, and Takeda of Japan. A factor promoting this exchange is that automakers in these countries want access to TPO technology and available resin sources.⁵⁰

TPO has traditionally been used in composites such as sheet molding compound used in automobile skin. Technological improvements allowing for unreinforced product applications is the future of TPO growth. Product examples include TPO molds for other plastic products and gel coats for marine use that offer greater blister resistance, flexibility, and UV stability.⁵¹

Growth in phenolic resins production will depend on increasing availability of diverse materials technology. In the United States, phenolic resins use trails in markets like transportation and construction, where resin properties such as low flame and smoke make them important from a safety perspective. Producers strive to offer a range of developments to meet performance requirements and maintain research and development programs, despite the current recession, that will enable them to take advantage of long-range phenolic resin applications. A developing transportation application is automotive parts that are resistant to flexible fuels, in particular, pure methanol or methanol blends, which would allow them to be applied in automotive fuel systems. Rogers Corp. is producing fuel system parts made of methanol-resistant phenolic resins. Resinold Chemical, in another application, is producing down-well parts for the oil industry.⁵²

Growth in PUR production during the 1990's is expected to be much lower than that of the 1980's, according to Gunter Oertel, director of Bayer AG's PUR division and president of the European Isocyanate Association. However, Mr. Oertel does not expect a recovery in PUR domestic sales until the second half of 1992 at the earliest. Environmental problems, in addition to the recession, contributed to the decline in PUR consumption, and thus production. The use of CFC as a blowing agent is perhaps

the most significant problem, but improving recyclability and fire safety are also major concerns. Progress has been made in these areas. The use of CFC as blowing agents in flexible foam is down approximately 50% from previous levels, and complete elimination is expected by 1994. Also, industrywide research and development continues on fire retardant PUR for application in furniture manufacture. ICI has developed a CFC-free, combustion-modified flexible PUR foam, and a phosphorous flame-retardant additive for reduced-CFC rigid-foam formulations is expected to be commercialized in 1992. In the other areas, the recyclability of PUR is affecting its ability to compete in the automotive and other markets. Miles Polymers, Dow, and ICI all introduced pilot recovery systems in 1991 to address this problem. Incineration of PUR waste was investigated in Germany by Bayer AG; its conclusion was that PUR waste could be incinerated without significant emission of pollutants and the energy released could be utilized.

In the United States, the Society of the Plastics Industry, Inc.'s Polyurethanes Recycling and Recovery Council is seeking ways to reclaim materials and energy from a minimum 25% of domestic PUR production by 1995.

Demand for engineering resins has been severely weakened as recession-strapped consumer markets, such as automotive and consumer durables, remain lackluster. In the future, engineering resins are expected to face stiff intermaterial competition. To that extent, producers have stepped up research and development for specialized materials that closely match application requirements, an action that is expected to widen the pool of workhorse engineering resins. Among the newly developed niche-oriented materials are Monsanto's ABS/PET chemical-resistant, impact-modified alloy, Du Pont's polyester analogs of Zytel FN nylon-acrylic rubber alloy with higher temperature retention of mechanical properties, and Hoechst Celanese's high-temperature polyester alloys. Also, Dow Chemical has developed a PC/ABS ignition resistant

alloy and Monsanto is touting a PC/ABS alloy with 10 degree higher heat resistance than competitive resins. Specialty grades of nylon with improved properties are on the horizon as are thermoplastic polyester with improved hydrolytic stability.

SYNTHETIC FIBERS

The current multiple-year recession has curbed fiber use in the apparel, automobile, construction, and industrial sectors. In the beginning of 1991, demand for synthetic fibers suffered a severe decline before gradually recovering later in the year. Overall shipments of synthetic fibers declined more than 1% in 1991, while the value of those shipments decreased more than 2% in both current and constant dollars. And, the longer term trend toward greater use of natural fibers in apparel and household-soft goods continued unabated in 1991, leading to a shrinking share for synthetic fibers in those markets. The competition between natural and synthetic fibers in recent years has caused several large manufacturers to reevaluate their positions in those markets and has precipitated conversions, closures, or outright sales of manufacturing facilities.

Background

Human beings have always sought to improve their surroundings and to maintain satisfactory living conditions. Through the years, fibers have played a very important and extensive role in that quest. Early examples of fiber use include clothing and tents for protection from harsh environments. Others include bows and arrows, which provided a means of acquiring food, and boats with sails, which provided transportation. All of those items were made of naturally occurring fibers because fibrous materials have high strength-to-weight ratios and possess excellent insulating properties.

The earliest fibers used were made from natural plant and animal products. Cotton, flax, sisal, wool, and silk were some of the more important ones. Later

mineral fibers made by spinning melted rocks were used for insulation. Synthetic organic-based fibers can imitate all of those natural (plant and animal) fibers and be further tailored to meet specific applications. Synthetic fibers are typically divided into two major groups, cellulosic, such as acetate and rayon, and noncellulosic, such as polyester and nylon. It was more than 60 years ago when scientists first began their search for methods of creating polymer fibers through chemical processes without using wood or natural substances. The first synthetic fiber, named rayon, followed by acetate, was developed in the early 1920's. During the 1930's, Dr. Wallace Carothers at the Du Pont Chemical Co. developed a polymeric fiber by combining two chemicals (hexamethylene diamine and adipic acid) extracted from coal or oil. It proved to have excellent strength and wear resistance. This unique material was named nylon. Nylon enjoyed extraordinary success, and later became a common household word with the introduction of nylon stockings.

With the 1940's came World War II, and almost the entire production of nylon was incorporated into war-related uses. At that time synthetic fibers, including nylon, rayon, and acetate, provided a mere 10% of America's fiber needs. However, synthetic fibers use grew with the postwar revolution in materials applications. By the mid-1980's, synthetic fibers provided approximately 75% of all the fibers used in America. In terms of major applications, synthetic fibers came to represent 51% of all fibers used in apparel, 60% in home fabrics, and 99% in carpeting. As for industrial uses, synthetic fibers have not fulfilled their potential with respect to their replacement capabilities for metals, minerals, and other traditional materials.

Products for Trade and Industry.—Synthetic fibers are used in all types of diverse applications. The most widely used fiber is polyester, employed both alone and as a blend with natural or other synthetic fibers. Some common applications for polyester include clothing, laundry bags, boat sails,

carpeting, fire hoses, conveyor belts, ropes, and geotextiles for highway construction. Nylon fibers also have a wide range of uses, including carpeting, upholstery, sleeping bags, hosiery, lingerie, and other clothing. Olefin fibers are incorporated in carpeting, drapery, and upholstery. They are used also in clothing, especially sportswear, because of their hydrophobic nature and wicking properties, which allow body moisture to pass to the surface of the fabric and away from the skin. Acrylic fibers are soft and warm and are used more commonly in blankets and sweaters. The cellulosic fibers, rayon and acetate, are used extensively in apparel and home furnishing and less often in industrial applications.

Technology.—In the past several years, exceedingly fine-diameter fibers have become the focus of research efforts by several fiber manufacturers. These "microfibers," usually less than one denier, are finding their way into new and different applications. Most manufacturers of microfibers have concentrated their emphasis on end products that have specific applications and fit special niche situations, such as filtering devices and nonwoven reinforcement materials. Microfiber producers anticipate that production will expand to a myriad of other industrial applications and into high-volume markets such as wearing apparel.

Polyester microfibers have been incorporated into a variety of new fabrics by blending them with wool or cotton. Due to their extraordinary strength, fabrics with unique, lightweight features can be produced. A substantial outlet for these fabrics would be men's and women's suits. In addition, the apparel industry views future development of these silk-like fabrics as a potential stimuli that would lure reluctant consumers back into a purchasing mode.

Economic Factors.—The U.S. textile and apparel industry is one of the most productive and efficient in the world. It provides economic security for a large

segment of the population associated with its various manufacturing and marketing components. But, this industry is finding it increasingly difficult to compete against foreign governments that subsidize their industries, pay workers a small fraction of U.S. wages, and impose severe restrictions on imports from the United States and other countries.

About 130 nations now send their textile and apparel goods to the United States, thereby controlling more than 50% of the domestic clothing market. Imports of these products grew so rapidly during the 1980's that many domestic plants closed down, putting more than 300,000 American workers out of work.

Operating Factors.—Federal law requires that textile products be labeled with three kinds of useful information. A sewn-in label identifying the country in which the product was made, a label or tag that includes those fibers that compose 5% or more of the item, and a permanent label giving care instructions.

Annual Review

Markets and Prices.—Overall domestic production of synthetic fibers in 1991 totaled almost 4.0 million tons, an increase of almost 1% from the 1990 level (table 16). This increase resulted from production gains in noncellulosic fibers, in particular polyester and polyolefins. Noncellulosic fibers production overall grew 1% to 3.8 million tons in 1991, while that of cellulosic fibers declined nearly 4% to 0.22 million tons. Polyester fibers registered the biggest production increase, up 7% in 1991 following a 11% drop 1 year earlier. Polyolefins fibers production, continuing an upward climb, increased 3% for the year. Among the largest volume synthetic fibers produced, polyester accounted for 39% of the total; followed by nylon, with 29%; and polyolefins, with 21%. (See table 16.)

In U.S. trade, the value of synthetic fibers imports grew 4% in 1991. Both cellulosic and noncellulosic fibers contributed to the increase. Cellulosic

fiber imports increased in part due to U.S. capacity constraints and a continuing demand for rayon fibers, while noncellulosic fiber imports rose slightly due to greater domestic polyester demand. Major U.S. suppliers, such as Canada, France, and Italy, posted sizable declines in synthetic fibers imported to the region. In contrast, Japan, the Republic of Korea, Taiwan, Thailand, and Yugoslavia each showed substantial increases in synthetic fibers imported to the United States. In fact, Taiwan surpassed Canada as the top U.S. supplier of noncellulosic fibers for the year.

The value of U.S. synthetic fiber exports climbed 12% in 1991, marking the fourth straight year of growth. Industry also witnessed a synthetic fibers trade surplus in 1991 that increased for the fourth consecutive year as robust export growth continued to overtake import growth, but not enough to help boost production to higher levels. Major export markets for U.S. synthetic fibers included Australia, Belgium-Luxembourg, Indonesia, Mexico, and Turkey. Italy and Spain were also important markets for U.S. synthetic fibers as exports to these regions grew.

Prices of synthetic fibers have been flat or have risen only slightly in recent years. An index for gray synthetic broadwovens, typical for the industry, showed a slight decrease in prices of less than 0.1% from the 1990 level. Over the period 1987-91, increases in price have averaged 2.2% per year.

Total U.S. shipments of olefin, polyester, and rayon staple fibers rose 5% to 1.3 million tons in 1991, compared with 1.2 million tons a year ago (table 17). The overall rise stemmed from increased fiber shipments of polyester staple, up 6%, and olefin staple, up 13%, during the year; shipments of rayon staple dropped 12%. Olefin staple fibers shipped to nonwovens increased 16% in 1991 and represented about 40% of all staples shipped to nonwoven markets. Olefin staple fiber shipments to other markets also increased during the year, by about 7% overall. Polyester staple fibers shipped to nonwovens dropped 1% in 1991, but shipments to other markets,

such as fiberfill and carpet, grew overall by 6%. In addition to olefin, polyester, and rayon fibers, nylon and acrylic fibers are used in nonwovens but only in very selected applications. As a result, these fibers represent a very small portion of total shipments to nonwoven markets by comparison, making them a negligible factor in the overall picture.⁵³ (See table 17.)

World Review.—World production of synthetic fibers dropped to 13.0 million tons in 1991, representing a continuing decline of about 3.7% from the 1990 level for those countries shown in table 18. Leading synthetic fiber producers included the United States, with a production of 4.0 million tons; China, with 1.9 million tons; Taiwan, with 1.5 million tons; and the former U.S.S.R., with 1.2 million tons. Only the Benelux countries and Italy registered production gains in Western Europe. All of the Eastern Europe countries posted substantial losses in production. The bright spot in foreign production was the Pacific Basin. Taiwan's synthetic fiber production rose 12.9%; China's production rose 12.4%, and South Korea's production rose 6.8%. A production index showed a slight increase in synthetic fiber production of slightly less than 1% for Japan. (See table 18.)

Outlook

Encouraging signs during the fourth quarter of 1991 may be the beginnings of a turnaround for the synthetic fibers industry. Overall production of synthetic fibers, led by strong growth in polyester, edged upward by yearend, albeit by only a small percentage. It is expected that synthetic fibers as a group will continue to grow in the near term as a result of strong domestic demand for both polyester and olefin fibers.

SYNTHETIC RUBBER

U.S. production of synthetic rubber in 1991 totaled 2.2 million tons, a decrease of 4% from the 1990 level. This is the

third consecutive year that synthetic rubber production has declined.

More than 50% of all commodity synthetic rubber produced in the United States is consumed by the tire industry. In recent years, however, commodity synthetic rubber has continued to lose market share, both on a volume and a dollar basis. Recessionary pressures, together with technology providing improved tire wear, have diminished industry performance. Total employment in the tire and tire products industry is estimated to have dropped 3.5% in 1991. World production of synthetic rubber in 1991 was approximately 10 million tons, and it appears that this amount is leveling off after several years of increases.

Background

Rubber goods, such as rubber coatings on fabrics, were manufactured in 1823 by Charles MacIntosh in Glasgow, Scotland. In 1838, modern industry was launched, when Charles Goodyear discovered that sulfur could be used to vulcanize rubber and that the cured material had a high degree of elasticity and no residual tackiness. Since that date, there have been many modifications and improvements in the formulation of natural rubber compounds. Also, many synthetic rubber polymers have been developed, and there is now a wide spectrum of natural and synthetic polymers that can be compounded to meet the requirements of different rubber end products.

The development of synthetic rubber was driven by a sharp rise in price due to demand exceeding natural rubber supply in the early 1900's. In 1909, F. Hofman in Germany succeeded in synthesizing isoprene from purely mineral resources and took out the world's first patent for a type of synthetic rubber. In 1929, two new types of synthetic rubber were discovered by the Germans. One was a copolymer of butadiene and styrene similar, but not identical, to the styrene-butadiene rubber (SBR) of today. The other was a copolymer of butadiene and acrylonitrile, more expensive than SBR, but offering a higher degree of oil

resistance. Between 1934 and the outbreak of World War II in 1939, Germany built five large plants capable of producing 175,000 tons of synthetic rubber per year. By 1939, Russia, following Germany's lead for national self-sufficiency, had developed a synthetic rubber industry with a production level of 90,000 tons per year.

In America, efforts were concentrated on the production of oil-resistant rubber. When the war started in 1942, all the main sources of natural rubber became controlled by the Japanese. That stronghold on natural rubber led to the institution of a vast governmental program to develop styrene-butadiene rubber in the United States and Canada. Ultimately, 51 government plants were constructed and operated in North America. Their output by the end of the war reached 700,000 tons per year.

The Korean war and the Suez Canal crisis in 1956 made it clear that orderly deliveries of natural and synthetic rubber from overseas at stable prices could not be relied upon during times of political unrest. These difficulties, combined with the effects of fluctuating currency exchange rates, led to a universal decision to build new synthetic rubber plants. During the late 1950's and early 1960's, plants became operational in Africa, Australia, Europe, Japan, and Latin America. The synthetic rubber industry had finally been established on a worldwide basis.

About 35% of all rubber currently used is natural, obtained from trees chiefly on plantations and small holdings in Malaysia, Indonesia, and other countries of Asia. Smaller areas of cultivation are in West Africa and South and Central America. The remaining 65% is synthetic; i.e., synthesized from petroleum and other minerals at plants mostly in industrialized countries. More than one-half of all rubber produced—natural or synthetic—is used to manufacture tires. The rest of the world's output goes toward the production of an extraordinary variety of industrial and consumer merchandise, ranging in size from huge dock fenders for ships to rubber stoppers, and in

technical sophistication, from domestic tap washers to artificial kidneys.

Examples of synthetic rubbers are styrene-butadiene rubber (SBR), polybutadiene rubber (BR), ethylene-propylene (EPR), nitrile rubber (NR), and other. This "other" category contains a variety of specialty elastomers that include polychloroprene, polyisoprene, silicones, urethanes, and TPE. TPE's are growing faster than the basic elastomers owing to this group's versatility and uniqueness in applications. Within the TPE family exists TPO. There is no industrywide definition of a TPO, nor even common terminology. TPO is also known as olefinic thermoplastic elastomer (OTPE) and elastomer modified polypropylene (EMPP). The most common designation, TPO, is usually applied to any blend of PP and rubber, and physical properties can vary widely.

Technology.—The distinguishing property of rubber is its elasticity. It can be stretched to as much as 10 times its original length without breaking and will return to its original size and shape, virtually unaltered. Rubber is waterproof and airtight, a combination of features found only among certain plastics. It has an astonishingly high abrasive resistance, far higher than steel or any other metal. Rubber is virtually unaffected by the corrosive action of the most common chemicals. Also, it can be bonded firmly to both textiles and steel.

In many of its applications, rubber is not used alone, but reinforced with other materials such as rayon, nylon, polyester, or glass fiber. The effect of the reinforcement is to increase the tensile strength while limiting its freedom to distort. The end result is a composite material that has limited elasticity and provides a combination of strength, toughness, and flexibility—which cannot be equalled in any other way.

Annual Review

Markets and Prices.—The current world market for synthetic rubber is controlled by a few large companies and

is characterized normally by only limited price competition among these large producers. The pricing of synthetic rubber is influenced by the cost of chemical monomers and other energy inputs, such as steam and electricity. In Western Europe and Japan, where oil (or naphtha) is the basic feedstock of the chemical industry and where these industries depend almost totally on imported crude, the cost and price of synthetic rubber monomers fluctuate directly with the cost of oil. However, in the United States, the petrochemical industry depends more on domestically produced natural gas and to a lesser degree on domestically produced oil. As a result, the production cost of synthetic rubber and market pricing tend to be more stable.

Domestic production of synthetic rubber in 1991 totaled 2.2 million tons, down 4% from its 1990 level and down 5% from its 1988 peak level of 2.3 million tons (table 19). Of the large volume products, styrene-butadiene rubber accounted for 38% of total production in 1991, compared with 40% in 1990. Polybutadiene rubber and ethylene-propylene rubber accounted for 19% and 10%, respectively, the same percentage shares held in 1990. (See table 19.)

World Review.—World production of synthetic rubber in 1991 totaled approximately 10 million tons; most of which was produced in a few countries. Japan, the United States, and Western Europe accounted for almost 50% of world production in 1991. France, Germany, and the United Kingdom, all major producers in Western Europe, combined for an output of more than 1.2 million tons in 1991, as shown in table 20. Compared to 1990, each of these countries posted decreases in production for the year. China was the only exception among the large-volume producers to show a production increase, up 6% in 1991 over the 1990 level. (See table 20.)

Current Research.—During recent years, TPE's that have properties similar to vulcanized rubber have been developed and marketed. The vulcanizing or curing process leads to a cross-linked thermoset structure. This structure cannot be softened or melted by reheating to the original molding temperature. Therefore, rejected parts and trim cannot be recycled. In direct contrast, TPE materials can be rapidly softened by heating to the mold temperature. In turn, scrap material and out of specification parts can be efficiently reprocessed. In addition, thermoplastic molding processes, such as injection and blow molding, can provide faster molding cycles than would be attainable with the usual compression or transfer molding of vulcanized rubbers. Also in the extrusion processes, TPE materials allow higher extrusion rates and may require considerably less capital investment in postcuring equipment. As research, design, and process engineers become more familiar with the extensive advantages of TPE's and potential new applications, the relative importance, as well as research expenditures, will probably accelerate.

Outlook

Because of the many advantages of TPE's over vulcanized rubber, it is not surprising that TPE materials have experienced a high rate of growth. Although TPE's currently account for only a relatively small percentage of the total U.S. consumption of elastomers, their rate of expansion is far more rapid than that of conventional cured rubber.

Market penetration is expected to increase for TPE compounds in footwear, adhesives, and wire coating industries. Other growth areas include industrial products such as hoses, bushings, flexible couplings, seals, and solvent coatings.

The International Institute of Synthetic Rubber Producers (IISRP, Houston) estimated a 3.4% decline in synthetic rubber consumption in 1991 for North America due to the economic recession. However, IISRP expects consumption to recover in the short term, increasing, on

average, 2.1% per year through 1996 to 3.1 million tons. Production increases are expected for specialty elastomers, polybutadiene, carboxylated styrene butadiene latex, and ethylene-propylene rubber. The thermoplastic elastomers are expected to exhibit the strongest growth rates, rising 7% per year to 389,000 tons by 1996. From 1992 to 1996, IISRP expects positive growth rates for nearly all elastomers.⁵⁴

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³Work cited in footnote 2.

⁴Fraser, S., A. Barsotti, and D. Rogich. *Sorting Out Material Issues*. BuMines. Resource. Policy, v. 4, No. 1, Mar. 1988, pp. 3-20.

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⁶Sullivan, D. E. *Trends in Plastic Usage*. Pres. at Polymer Materials Systems Analysis, Technology Transfer Seminar, Washington, DC, Nov. 6, 1989, 85 pp.; available from D. E. Sullivan, MAFO, Denver, CO.

⁷Oil & Gas Journal. Mar. 9, 1992, p. 23.

⁸U.S. Department of Energy. *Energy Information Administration. Weekly Petroleum Status Report*, (DOE/EIA-0208(9243)). Weekly Data Ended Oct. 23, 1992, p. 17.

⁹U.S. Department of Labor. *Bureau of Labor Statistics. Supplement to Employment and Earnings*.

¹⁰Chemical & Engineering News. *Facts and Figures for the Chemical Industry*. June 29, 1992, pp. 32-75.

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¹²Modern Plastics. *1991 Resin Sales Took a Step Back*. Jan. 1992, p. 85.

¹³Work cited in footnote 10.

¹⁴Chemical & Engineering News. Aug. 3, 1992, p. 22.

¹⁵Plastics News. May 13, 1991, p. 5.

¹⁶Work cited in footnote 10.

¹⁷Modern Plastics. *Far East Buildup in Polyolefins Will Reshape Global Market for These Resins*. Feb. 1992, pp. 18-19.

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²⁰Panar, M. *Personal communication*, Jan. 1989; available upon request from Catherine Kilgore, BuMines, Denver, CO.

²¹Plastics Engineering. Jan. 1992.

²²Plastics News. Sept. 16, 1991, p. 51.

²³Modern Plastics. *Resin 1992 Supply Patterns Are Changing*. Jan. 1992, pp. 53-81.

²⁴Work cited in footnote 23.

²⁵Plastics News. Aug. 10, 1992, p. 3.

²⁶———. Mar. 18, 1991.

²⁷———. Dec. 16, 1991, p. 1.

²⁸Chemical Engineering. *Plastics Reborn*. July 1992, pp. 30-35.

²⁹Plastics News. Jan. 21, 1991, p. 12.

³⁰———. Nov. 11, 1991.

³¹Plastics Technology. Jan. 1991, p. 107.

³²———. Feb. 1991, p. 117.

³³———. July 1991, p. 99.

³⁴———. Nov. 1991, p. 69.

³⁵Modern Plastics. May 1991.

- ³⁶Work cited in footnote 23.
³⁷Work cited in footnote 23.
³⁸Work cited in footnote 23.
³⁹Work cited in footnote 23.
⁴⁰Work cited in footnote 23.
⁴¹Work cited in footnote 23.
⁴²Department of Commerce. 1992 U.S. Industrial Outlook, Jan. 1992, p. 13-2.
⁴³Work cited in footnote 23.
⁴⁴Work cited in footnote 23.
⁴⁵Work cited in footnote 23.
⁴⁶Work cited in footnote 23.
⁴⁷Work cited in footnote 23.
⁴⁸Work cited in footnote 23.
⁴⁹Work cited in footnote 23.
⁵⁰Work cited in footnote 23.
⁵¹Work cited in footnote 23.
⁵²Work cited in footnote 23.
⁵³Nonwoven Industry. June 1992, pp. 28-31.
⁵⁴Chemical Week. Jan. 22, 1992, p. 29.

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TABLE 1
CONSUMPTION OF MAJOR FEEDSTOCKS FOR PLASTICS, 1990

Feedstock	Consumed in plastics	
	Million pounds	Percent of total
Benzene	9,200	68
Butadiene	225	11
Ethylene	26,500	75
Methane	2,700	(¹)
Naphthalene	300	65
Propylene	12,100	64
Toluene	700	11
Xylene	1,400	22

¹Less than 0.5%.

Source: Rauch Associates, Inc.

TABLE 2
PETROCHEMICAL FEEDSTOCKS (CONTRACT PRICES)

		January 1991	July 1991	December 1991
Benzene	dollars per gallon	1.40	1.10	1.30
Ethylene	cents per pound	29.30	20.50	21
Propylene	do.	24.50	18	16
Styrene	do.	42-43	33.50	27

Source: Plastics World.

TABLE 3
**U.S. PLASTICS, FIBERS, AND RUBBER WORK FORCE
CHARACTERISTICS**

	1989	1990	1991
Industrial employment (thousands):	182	181	177
Women employed	40.3	41.4	41.4
Men employed	141.7	139.6	135.6
Production workers (thousands)	119	116	110
Average workweek (hours)	43.1	42.5	42.6
Average hourly earnings (dollars):			
Plastics, fibers, and rubber	13.06	13.44	14.02
All manufacturing	10.47	10.84	11.18

Source: Chemical & Engineering News and U.S. Bureau of Labor Statistics.

TABLE 4
SALIENT U.S. ORGANIC MATERIALS STATISTICS

(Million metric tons, unless otherwise specified)

	1987	1988	1989	1990	1991
Petrochemical industries:					
Production, total feedstocks: ¹	55.79	56.06	55.66	57.75	65.09
Production, resins ²	29.75	31.89	31.61	33.04	33.32
Production, others ³	26.04	24.17	24.05	24.70	31.77
Imports for consumption ^f	6.87	9.63	9.18	10.11	8.92
Exports ⁴	1.46	1.99	2.19	2.17	1.26
Consumption, apparent primary	61.01	63.61	63.17	64.92	72.96
Price, dollars per metric ton ⁵	\$110.41	\$91.84	\$113.75	\$134.36	\$114.54
Stocks, yearend ⁶	4.42	4.51	3.99	4.74	4.53
Lubricants, miscellaneous products, waxes:					
Production	12.51	12.99	12.78	12.51	12.10
Imports for consumption	.90	.73	.74	.74	.58
Exports	1.32	1.46	1.15	1.19	1.04
Consumption, apparent primary	12.13	12.35	12.35	12.29	11.65
Price, dollars per metric ton ⁵	\$111.60	\$91.30	\$117.30	\$148.90	\$124.50
Stocks, yearend	2.48	2.39	2.41	2.18	2.17
Petroleum coke and coal:					
Production	12.00	12.07	11.47	13.05	13.07
Imports for consumption ^f	.02	.03	.02	.04	.04
Exports ⁶	4.26	4.44	4.21	4.58	4.61
Consumption, apparent primary	7.62	7.62	7.26	8.53	8.35
Price, dollars per metric ton ⁵	\$76.54	\$63.52	\$78.47	\$98.95	\$80.94
Stocks, yearend ⁶	.37	.41	.43	.41	.52
Asphalt and road oil:					
Production	26.09	26.72	25.52	25.02	25.69
Imports for consumption	2.19	1.90	1.85	1.91	1.67
Exports	.05	.06	.19	.17	.19
Consumption, apparent primary	28.05	28.22	27.23	27.06	26.57
Price, dollars per metric ton ⁵	\$107.00	\$87.60	\$110.40	\$139.10	\$114.60
Stocks, yearend	3.10	3.44	3.39	3.09	3.69

¹Revised.

²Total feedstocks are composed of liquefied petroleum gases, petrochemical feedstocks, special naphthas, and dry natural gas as defined in table 13 of the Annual Energy Review 1991.

³Resins are composed of feedstocks for the production of plastics, synthetic fibers, and synthetic rubber.

⁴Others are composed of those feedstocks used in the production of pesticides, coatings, solvents, and other petrochemicals.

⁵Dry natural gas is not included.

⁶Price is based on the British thermal unit value of fossil fuels as close to the point of production as possible as given in table 30 of the Annual Energy Review 1991.

⁷Coal is not included.

Sources: Chemical & Engineering News, Annual Energy Review 1991, Petroleum Supply Annual 1991, and Modern Plastics.

TABLE 5
HISTORICAL DEVELOPMENT OF POLYMERS

Date	Event
1862	Alexander Parkes introduced the cellulose nitrate, Parkesine.
1868	J. S. Hyatt discovered a cellulose nitrate and the injection molding machine.
1870	Celluloid patent granted to J. S. Hyatt in the United States.
1877	A. Kekule postulated that natural products are long-chain molecules.
1893	E. Fischer verified that the structure of cellulose is indeed a macromolecule.
1909	L. H. Baekeland discovered phenol formaldehyde resins (Bakelite).
1919	Cellulose acetate available as molding material.
1924	H. Staudinger proposed the linear chain structure for polystyrene.
1927	Introduction of polyvinyl chloride.
1928	O. Rohm commercialized polymethyl methacrylate (PMMA).
1929	Introduction of urea-formaldehyde resins.
1930	First production of polystyrene (PS).
1933	Discovery of polyethylene (LDPE).
1934	Production of polymethyl methacrylate sheet.
1935	W. H. Carothers first synthesized nylon 6/6.
1936	Introduction of polyacrylonitrile, styrene-acrylonitrile copolymers, and polyvinyl acetate.
1937	O. Bayer discovered polyurethanes.
1938	P. Schlack discovered nylon-6 and epoxy resins. R. J. Plunkett discovered the polymerization of tetrafluoroethylene (PTFE). High-pressure polymerization of ethylene was introduced.
1939	Commercial production of LDPE, development of epoxide resins.
1940	Production of PVC, melamine formaldehyde laminates (Formica). G. E. Rochow discovered the direct process for the manufacture of chlorosilanes, the raw material for silicone resins.
1941	Development of fiber-forming polyesters. J. R. Whinfield and J. T. Dickenson discovered polyethylene terephthalate (PET).
1942	Commercial introduction of PAN fibers (Orlon).
1948	Introduction of acrylonitrile-butadiene-styrene, used to manufacture luggage.
1950	Commercial production of PTFE (Teflon).
1952	K. Ziegler developed catalysts for the low-pressure polymerization of ethylene.
1953	G. Natta used Ziegler catalysts to synthesize stereoregular polypropylene (PP). H. Schnell discovered polycarbonate. First PET (Dacron) plant began production.
1955	Development of HDPE and PP.
1956	A. S. Hay discovered polyphenylene oxide (PPO).
1958	Commercial introduction of polyacetal.
1959	Production of acetal (Delrin) and polycarbonate (Makrolon).
1960's	Development of lyotropic LCP films and spun fibers (aramid fibers).
1960's	Introduction of aromatic polyester (Ekonol) for plasma coating.
1963	Introduction of polyimides (Polymer SP).
1964	Production of PPO components for appliances, electrical connectors.
1965	Commercial use of polysulfone (Udel) for electrical components.
1966	Modified PPO introduced as Noryl, cheaper and easier to process than PPO.
1967	Polyarylsulfone introduced as Astrel 360.
1968	Polyphenylene sulfide (PPS) introduced as Ryton.
1972	Polyethersulfone (Vitrex) used in aerospace and automotive applications.
1973	Introduction of Kevlar aramid fibers.
1970's	Introduction of Rynite, a very rigid PET. Blow molding of PET bottles became popular.
1977	Commercial production of linear low-density polyethylene (LLDPE). Polyphenylsulfone (Radel).
1978	ICI first markets PEEK, a high-temperature resistant material used in aerospace and computer applications.
1982	Modified polyimide (polyether-imide) introduced (Utem) for use in high-performance fiberoptic components, coextruded food packaging, and advanced composites.
1984	Thermotropic (melt-processible) liquid crystal polymers (LCP) introduced (Xydar) consumed mainly by Tupperware.

TABLE 6
U.S. PRODUCTION CAPACITY, SELECTED RESINS

(Thousand metric tons)

Resin	1987	1988	1989	1990*	1991
Polyethylene:					
Capacity	8,386	9,076	9,534	10,185	10,808
Percent utilization rate	95.1	94.0	84.7	86.8	87.3
Polypropylene:					
Capacity	3,114	3,622	4,021	4,118	4,314
Percent utilization rate	96.9	91.1	81.6	91.5	87.6
Polystyrene:					
Capacity	2,368	2,587	2,740	2,544	2,671
Percent utilization rate	91.6	91.0	84.5	89.5	84.1
PVC:					
Capacity	3,780	4,040	4,213	4,257	4,390
Percent utilization rate	95.6	93.8	91.3	96.9	94.7

*Revised.

Source: The Society of the Plastics Industry, Inc., Facts & Figures of the U.S. Plastics Industry.

TABLE 7
PLASTICS FABRICATION, BY PROCESS AND TYPE OF PROCESSOR

Process	Total ¹	Percent of total		
		Captive	Custom	Supplier
Blow molding	2,469	56	38	6
Calendering	559	65	24	11
Compression-transfer molding	1,374	67	28	5
Extrusion	5,154	55	38	7
Foam processing	2,742	58	35	7
Injection molding	9,748	57	38	5
Reinforced processing	2,573	66	29	5
RIM	857	57	36	7
Rotational molding	649	59	34	7
Thermoforming	2,876	59	37	4
Total	29,000	XX	XX	XX

XX Not applicable.

¹Plants engaged in one or more primary processes.

Source: Rauch Associates, Inc.

TABLE 8
PROCESSING OF PLASTICS, BY PRINCIPAL METHODS

(Thousand metric tons)

Year	Extrusion		Blow molding		Injection molding		Total sales
	Weight	Percent	Weight	Percent	Weight	Percent	Weight
1970	2,337	27.7	400	4.7	645	7.7	8,434
1975	2,985	28.0	470	4.4	1,397	8.6	10,650
1980	5,439	33.6	1,021	6.3	1,397	8.6	16,182
1985	7,589	35.9	1,449	6.9	1,939	9.2	21,112
1990	10,501	37.6	2,036	7.3	2,419	8.7	27,908
1991	9,796	35.5	2,036	7.4	2,419	8.8	27,604

Source: Modern Plastics.

TABLE 9
U.S. PLASTICS PROCESSING MACHINERY SALES

(Number of units)

	1990		1991	
	Quantity	Percent	Quantity	Percent
Injection molding machines:				
U.S. made	1,770	42	1,611	41
Imported	2,467	58	2,366	59
Total	4,237	100	3,977	100
Extrusion machines:				
U.S. made	1,007	57	952	72
Imported	775	43	374	28
Total	1,782	100	1,326	100

Sources: U.S. Department of Commerce, The Society of the Plastics Industry, Inc., and European Plastics News.

TABLE 10
PLASTIC PRICES

(Cents per pound)

	January 1991	July 1991	December 1991
HDPE, injection molding	45-48	34-36	34-37
HDPE, recycled, natural	30-33	33-35	22-29
LDPE, liner grade	45	27	29-33
PET, recycled, clear	35-36	35-36	33-38
Polypropylene	43-47	33	36-37
Polypropylene, recycled	16-26	16-26	8-12
Polystyrene	57-59	38-40	42-43
PVC	37	25-26	27
PVC, recycled	18-22	18-22	15-20

Sources: Plastics World and Plastics News.

TABLE 11
U.S. PRODUCTION OF SELECTED THERMOPLASTICS AND THERMOSETS

(Thousand metric tons)

	1990	1991
Thermoplastic resins:		
LDPE	5,057	5,253
HDPE	3,782	4,180
Polypropylene	3,769	3,781
Polystyrene	2,278	2,248
Styrene-acrylonitrile	61	49
Acrylonitrile-butadiene-styrene	1,066	1,038
Polyamide, nylon type	253	261
PVC	4,126	4,159
Other vinyl resins	96	86
Thermoplastic polyester	852	957
Other thermoplastics	1,202	1,189
Total	22,542	23,201
Thermoset resins:		
Epoxy	226	241
Melamine	92	89
Phenolic	1,336	1,206
Polyester	554	488
Urea	679	673
Polyurethane	1,492	1,354
Total	4,379	4,051

Sources: Chemical & Engineering News and Modern Plastics.

TABLE 12
U.S. CONSUMPTION OF SELECTED RESINS

Resin	Consumption (thousand metric tons)	
	1990	1991
LDPE	4,896	4,688
HDPE	3,861	3,854
PP	3,023	3,012
PVC	3,724	3,505
PS	2,239	2,116
ABS	477	457

Source: Modern Plastics, Jan. 1992.

TABLE 13
U.S. PLASTIC RESIN SALES

(Thousand metric tons)

	1987	1988	1989	1990	1991
ABS	548	580	561	527	510
Acrylic	302	316	335	315	305
Alkyd	138	145	147	145	143
All others	118	131	141	150	156
Cellulosics	40	41	41	36	38
Epoxy	190	212	219	210	194
EVA	517	503	475	497	506
HDPE	3,699	3,667	3,707	4,009	4,170
LDPE	2,331	2,962	2,975	2,770	2,827
LLDPE	1,507	1,500	1,763	2,160	2,175
Nylon	226	260	263	263	252
Other styrenics	569	499	535	566	535
Other vinyls	414	431	408	287	254
PBT/PCT/PET	802	927	951	1,060	1,156
Phenolic	1,364	1,385	1,282	1,333	1,159
Polacetal	55	63	65	65	64
Polycarbonate	178	267	283	281	273
Polyester, unsaturated	596	623	598	557	490
Polyphenylene alloys	77	78	89	90	88
Polyurethane	1,283	1,467	1,462	1,492	1,354
PP	3,048	3,215	3,313	3,737	3,699
PS	2,204	2,280	2,327	2,290	2,212
PVC	3,666	3,759	3,849	4,080	4,141
SAN	53	66	49	61	53
Thermoplastic elastomers	200	223	246	265	265
Urea/melamine	710	687	626	759	665
Total¹	24,835	26,287	26,712	27,805	27,487

¹Revised.

¹Data may not add to totals shown because of independent rounding.

²Includes only polyvinyl butyral, polyvinyl formal, and polyvinylidene.

Source: Modern Plastics.

TABLE 14
U.S. IMPORT AND EXPORT TRADE SUMMARY
OF SELECTED RESINS

(Thousand metric tons)

	1990	1991
LDPE:		
Exports	530	820
Imports	476	384
Net exports	54	436
HDPE:		
Exports	331	473
Imports	182	157
Net exports	149	316
PP:		
Exports	740	708
Imports	25	21
Net exports	714	687
PVC:		
Exports	429	684
Imports	73	48
Net exports	356	636
PS:		
Exports	85	118
Imports	34	22
Net exports	51	96
ABS:		
Exports	84	87
Imports	34	34
Net exports	50	53

NOTE.—Net exports (exports minus imports). All categories are independently rounded.

Source: Modern Plastics, Jan. 1992.

TABLE 15
WORLD SALES OF PLASTIC
RESINS

(Thousand metric tons)

	1990	1991
Australia	985	948
Bulgaria	256	180
Canada:		
ABS	64	62
HDPE	393	420
LDPE	1,230	1,221
PP	277	296
PVC	452	375
PS	186	166
Total ¹	2,602	2,540
China	2,249	2,640
Czechoslovakia	1,174	944
France:		
PE	1,116	1,199
PP	778	812
PS	541	527
PVC	1,027	1,048
Total ¹	3,462	3,586
Germany:		
PE	1,476	1,366
PP	508	528
PVC	1,321	1,161
Total ¹	3,305	3,055
Hungary	603	601
Italy:		
PE	931	937
PS	353	381
PVC	618	617
Total ¹	1,902	1,935
Japan:		
PE	2,888	2,982
Phenolic resins	385	383
PP	1,942	1,963
PS	2,097	2,121
PVC	2,049	2,055
Total ¹	9,361	9,504
Poland	627	593
Romania	473	349
Taiwan	1,460	1,742
U.S.S.R.	4,532	3,975
United Kingdom:		
PE	336	376
PP	296	315
PVC	348	322
Total ¹	980	1,013

See footnotes at end of table.

TABLE 15—Continued
WORLD SALES OF PLASTIC
RESINS

(Thousand metric tons)

	1990	1991
United States	¹ 27,805	27,487
Grand total ²	¹ 61,776	61,092

¹Revised.

²Country subtotals are for resins shown only.

³Total is for countries and resins listed only.

Sources: Modern Plastics and Chemical & Engineering News.

TABLE 16
U.S. SYNTHETIC FIBERS PRODUCTION

(Thousand metric tons)

	1987	1988	1989	1990	1991
Noncellulosic fibers:					
Acrylic	269	267	² 247	230	206
Nylon	¹ 1,221	¹ 1,212	¹ 1,244	¹ 1,208	1,152
Olefin	678	⁷ 721	⁷ 744	⁸ 827	847
Polyester	¹ 1,608	¹ 1,671	¹ 1,632	¹ 1,451	1,548
Cellulosic fibers	² 275	279	263	229	220
Total	⁴ 4,051	⁴ 4,150	⁴ 4,130	³ 3,945	3,973

¹Revised.

Source: Chemical & Engineering News.

TABLE 17
DOMESTIC SHIPMENTS OF STAPLE FIBERS, BY MARKET

(Thousand metric tons)

Fiber	Market	1987	1988	1989	1990	1991
Rayon	Shipments to nonwovens	57	55	44	33	32
	All others	117	120	109	100	84
	Total domestics¹	174	175	153	132	116
Polyester	Shipments to nonwovens	93	111	123	108	108
	All others	906	938	902	805	858
	Total domestics¹	998	1,049	1,026	914	965
Olefin	Shipments to nonwovens	89	82	88	106	123
	All others	65	74	76	70	75
	Total domestics¹	155	156	165	176	199
Total¹		1,327	1,380	1,344	1,222	1,280

¹Data may not add to totals shown because of independent rounding.

Source: Nonwovens Industry, June 1992.

TABLE 18
SYNTHETIC FIBERS PRODUCTION, SELECTED COUNTRIES

(Thousand metric tons)

	1988	1989	1990	1991
Austria	163	*172	173	157
Benelux countries	229	*291	311	326
Bulgaria	72	*71	*59	NA
China	1,284	1,466	*1,655	1,860
Czechoslovakia	205	208	200	137
Finland	63	68	69	53
France	193	180	156	118
Germany	*996	*1,015	*1,019	977
Hungary	37	36	30	30
Ireland	80	94	93	93
Italy	*691	*676	*694	727
Korea, Republic of ¹	593	654	730	780
Poland	245	238	149	106
Portugal	59	65	64	64
Romania	297	273	*209	144
Spain	*305	*309	301	283
Switzerland	116	120	118	102
Taiwan ¹	1,100	1,193	1,290	1,457
Turkey	278	302	*252	NA
U.S.S.R.	1,555	1,557	*1,477	*1,175
United Kingdom	342	*340	350	332
United States	*4,150	*4,130	*3,945	3,973
Yugoslavia	169	159	148	*101
Total ²	*13,222	*13,617	*13,492	*12,995

*Estimated. *Revised. NA Not available.

¹Polyester fibers only.

²Total is for countries listed only.

Source: Chemical & Engineering News.

TABLE 19
U.S. SYNTHETIC RUBBER PRODUCTION

(Thousand metric tons)

	1987	1988	1989	1990	1991
Ethylene-propylene	254	263	260	*266	232
Nitrile	69	76	*70	56	57
Polybutadiene	371	407	*452	*412	415
Styrene-butadiene rubber	850	909	*884	853	843
Other ¹	638	679	*662	*725	668
Total	2,182	2,334	*2,328	*2,312	2,215

*Revised.

¹Includes butyl, polychloroprene, polyisoprene, silicone, and other synthetic elastomers.

Source: Chemical & Engineering News.

TABLE 20
SYNTHETIC RUBBER PRODUCTION, SELECTED COUNTRIES

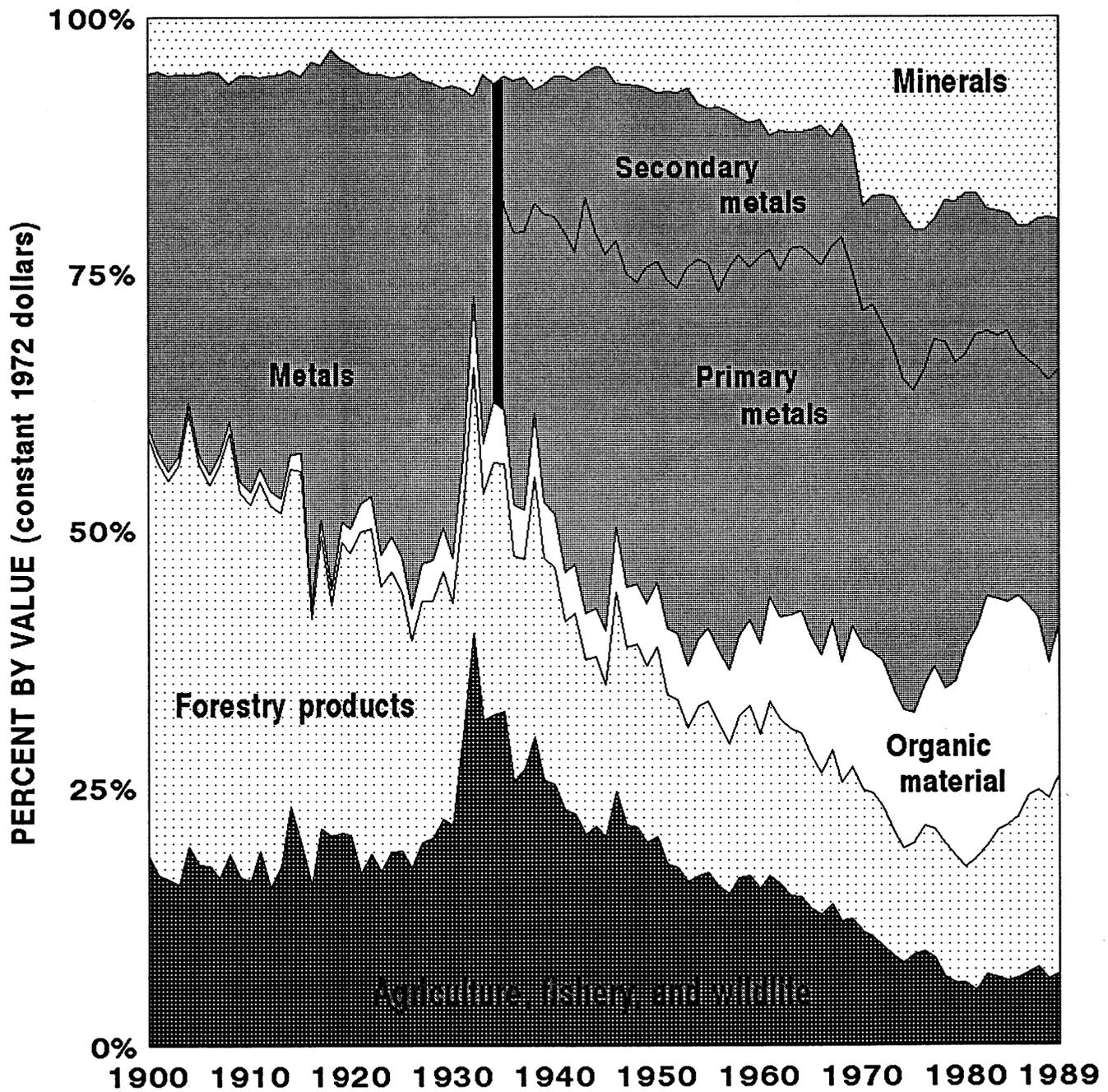
(Thousand metric tons)

Country	1990	1991
Bulgaria	24	NA
China	316	335
Czechoslovakia	'69	45
France	'523	470
Germany	'524	511
Japan	1,426	1,368
Poland	103	80
Romania	102	55
U.S.S.R.	2,400	NA
United Kingdom	'298	273
United States	'2,312	2,215

Revised. NA Not available.

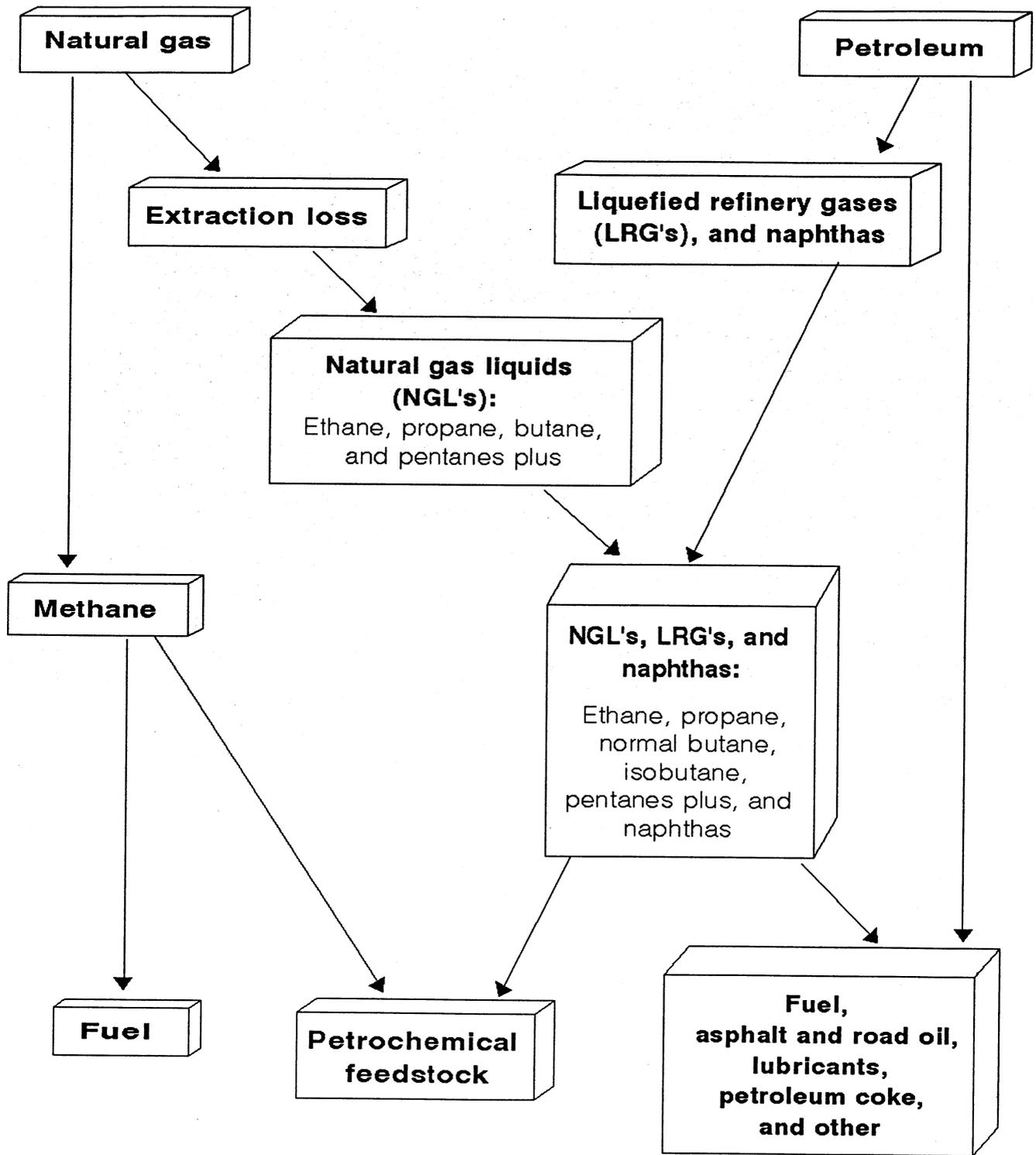
Source: Chemical & Engineering News.

FIGURE 1
 U.S. CONSUMPTION OF RAW MATERIALS IN NONFOOD AND NONFUEL USES



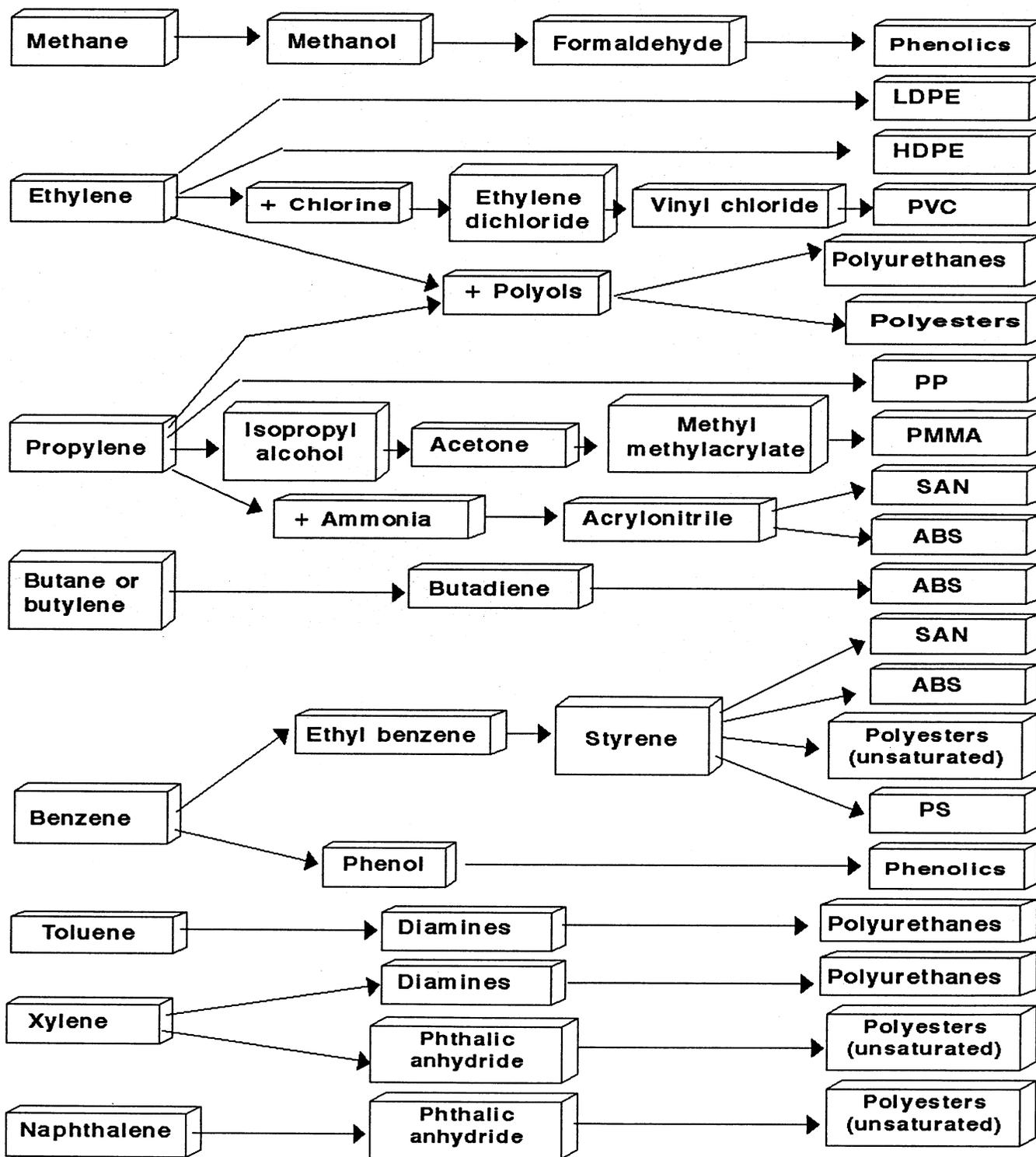
Source: U.S. Bureau of Mines.

FIGURE 2
MATERIALS FLOW FROM WELL TO FEEDSTOCK



Source: U.S. Bureau of Mines

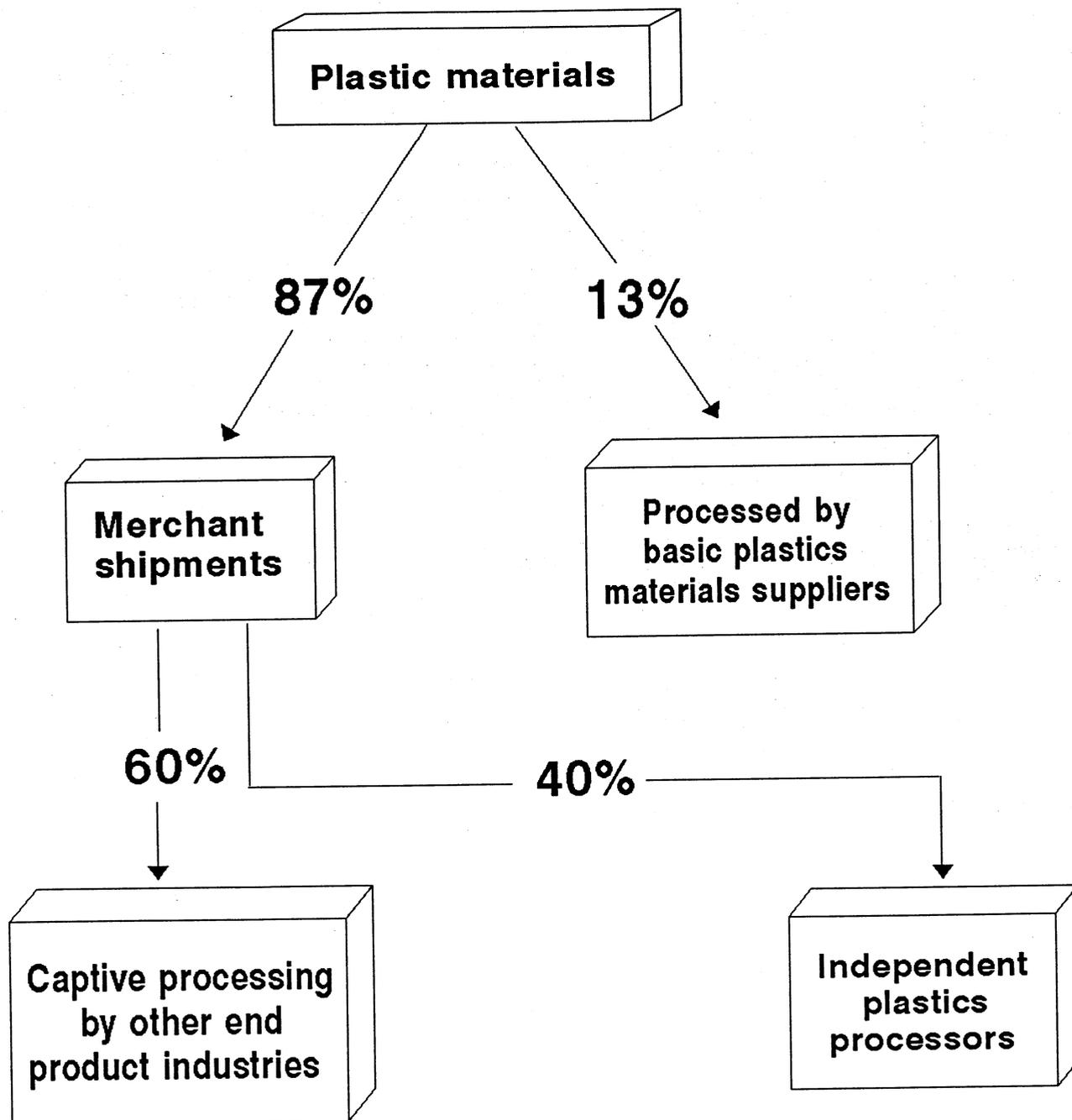
FIGURE 3
MATERIALS FLOW FROM PETROCHEMICAL FEEDSTOCKS TO PLASTIC RESINS



Source: U.S. Bureau of Mines.

FIGURE 4
STRUCTURE OF THE PLASTICS PROCESSING SECTOR

Percentage of structural consumption



Source: Rauch Associates, Inc.

PEAT

By Raymond L. Cantrell

Mr. Cantrell, a physical scientist with 28 years of U.S. Bureau of Mines and industry experience, has served as the Bureau peat commodity specialist since entering public service in 1988. Virginia Harper, statistical assistant, monitored the survey and also prepared domestic data tables. International data tables were prepared by staff, international data.

Peat is a unique natural organic material of botanical origin and commercial significance that is found deposited in abundant quantities at the Earth's surface, where it plays an active role in the dynamics of our planet's ecosystem. Peat deposits function as natural hydrological control sources for vast areas of wetlands, provide an effective natural filtration medium for waterborne contaminants, and also serve as a biomass-related carbon link between the land and air. Today, peat deposits cover about 1 billion acres, or 4.4% of the Earth's total landmass.

The global horticultural and agricultural sectors consume significant quantities of peat for use as a plant growth medium and soil amendment. In addition to its large volume use by the home gardener and professional nursery and landscape businesses, peat also enjoys substantial use in a myriad of industrial applications and consumer products, including potting soils, turf cultivation, golf course greens construction and course maintenance, mushroom cultivation and earthworm culture, poultry litter, fertilizers, composting, seed inoculants, humic acid extracts, toxic waste filtration, oil absorption, hygienic products, and fuel for electrical power generation.

In 1991, the U.S. peat industry continued to be adversely impacted by the recessionary forces of a weakened economy and the pressure of Canadian sphagnum peat, peat mixtures, and other articles of peat. The Bureau's annual survey of domestic peat producers in the 48 contiguous United States reflected a

9% decline in production accompanied by the closure of 6 U.S. peat operations. The value of producer sales, f.o.b. plant, dropped 7%, on a relatively unchanged volume of 0.8 million short tons. A 10% decline in packaged peat prices, f.o.b. plant, was responsible for the overall drop in prices and profitability. The deviation between domestic production and sales reflected an inventory drawdown at the plant level, together with relatively strong movement of field (offsite) inventories.

Alaskan peat production in 1991 was estimated at 75,000 yards by personnel of the State Division of Geological & Geophysical Surveys, Fairbanks, AK. The Alaskan peat carried a value of \$450,000, or \$6 per yard, f.o.b. plant, representing an increase of 15% by volume and 13% in value.

Canadian peat movement across the U.S. border reached new records in terms of volume, value, and market share. Canadian peat was shipped predominately from the Provinces of Quebec and New Brunswick in eastern Canada and from Alberta, Manitoba, and Saskatchewan, in western Canada, and accounted for a record 48% of the total U.S. peat supply. Canadian import volume was a record 631,000 short tons and was valued at \$95.7 million, equating to a price of \$152 per ton at U.S. Customs.

The total U.S. peat supply was valued at \$114 million based on f.o.b. domestic plant and U.S. import Customs values. The monetary significance of peat as a value-added product at the retail level in the United States is many times greater

and may exceed \$1 billion. (See table 1 and figure 1.)

DOMESTIC DATA COVERAGE

The Division of Statistics and Information Services, U.S. Bureau of Mines, conducts an annual survey of domestic peat producers in the 48 contiguous United States. Information obtained from the Bureau's voluntary canvass was used to develop data tables for publication. Of the 105 peat operations surveyed in 1991, 76 were reported to be active, 20 idle, and 9 were reported to have closed permanently. Estimates were made for active operations that did not report data, based on past trends.

Alaskan peat producers were surveyed independently by the Department of Natural Resources, Division of Geological & Geophysical Surveys, Fairbanks, AK. In 1991, operations in the Anchorage and Fairbanks areas reported active production.

BACKGROUND

The U.S. peat industry developed from small "mom and pop" operations that today comprise about 70% of all active peat operations and account for about 20% of total production. They provide essential peat supplies to surrounding communities that contribute significantly to cash-flow and liquidity within local economies. About 80% of U.S. peat is produced in high-volume operations by 30% of the producers. Large operations

move peat in interstate commerce owing to economies of scale.

Peat deposits developed typically through the gradual decomposition of plant matter under anaerobic conditions in shallow aquatic basins. Most of the peat deposits in existence today lie at the Earth's surface and have formed since the last ice age approximately 10,000 years ago, although much older Pleistocene peats, typical of the deposits buried beneath the sands of Trail Ridge in Bradford and Clay Counties, FL, are known. Peat is a precursor of lignite and coal.

Peatlands, or mires as they are sometimes called, are more extensive in the temperate, boreal, and subarctic zones of the Northern Hemisphere and more limited in the cool and humid zones of the Southern Hemisphere. Peat deposits may be called bogs, fens, or "poor fens"—combinations of bog, fen, or swamp formations—depending on the aquatic mechanisms of the particular setting.

Most of the world's peatlands are classified as bogs. Bog is from the Celtic word "bocc," meaning "soft," which is an apt description for these waterlogged terrains. A bog is typically an acidic peatland that depends principally on rainfall to perpetuate the waterlogged conditions necessary for its survival. Because there is less decomposition in these nutrient-poor, acidic environments, the more fibrous peats—sphagnum moss, hypnum moss, and reed-sedge—may be found as the predominant species in the upper zone of the deposit.

The term "fen," as derived from the Anglo-Saxon language, translates to "mud" in modern day English. Fens are peatlands that depend mainly on ground water sources for their formation and survival and, thus, are less dependent on rainfall. Fens, unlike bogs, are found in less acidic nutrient-rich environments. Plant matter tends to decompose more rapidly under these relatively chemically neutral conditions, leading to a less fibrous, more mineralized material that in advanced stages of decomposition is known as muck or peaty muck. The majority of fens are over sites of sand

and gravel deposits that are buried within more clayey glacial materials (intertill), providing a ground water seep over which the peat forms. It, therefore, is not uncommon to find fens situated on hillsides.¹

Definitions, Grades, and Specifications

Methods adopted by the American Society for Testing and Materials (ASTM) find widespread use for the characterization of peat matter.² The ASTM Classification of Peats, Mosses, Humus, and Related Products requires the use of three parameters: ash content, fiber content, and botanical composition. Earthy organic materials must have an ash content of no more than 25% by dry weight to be classified as "peat." Botanical characteristics and fiber content govern peat types. Fibrous peat is defined as material retained on an ASTM No. 100 screen; that is, material 0.15 millimeters or larger.

Sphagnum moss peats must have a fiber content greater than 66%, all of which must be derived from the genus Sphagnum, as determined by screening and botanical analysis. Hypnum moss peats must have a 33% minimum fiber content, of which at least 50% must be derived from the genus Hypnum. Reed-sedge peats must have a 33% minimum fiber content containing more than 50% reed-sedge and other nonmoss fibers.

The U.S. Department of Agriculture Soil Conservation Service subdivides peat into three general categories: (1) fibric (peat moss), which is composed of sphagnum, hypnum, and other mosses; (2) hemic (reed-sedge), which is formed from reeds, sedges, swamp plants, and trees; and (3) sapric (humus), which is composed of materials that are decomposed beyond recognition of botanical origin.³

Fibric peats such as sphagnum and hypnum are relatively young moss species that are light in color in comparison to other peat varieties. Fibric peats, because of the lower order of decomposition, have a relatively high water-retention capacity and, in general, are quite acidic. Fibric peats have a low

bulk density that averages about 250 pounds per cubic yard on an air-dried basis and very little ash. These peats are not suitable for fuel owing to the low degree of decomposition.

Hemic, or reed-sedge peats, are somewhat older and more decomposed than fibric peats and originate from reeds, sedges, and other nonmoss type plants. Hemic peats are considered to be intermediate between fibric and sapric in degree of decomposition, bulk density, and ash content. The average density of air-dried reed-sedge peat is about 950 pounds per cubic yard. Reed-sedge peats are usually slightly acidic and have a high energy value owing to fixed carbon content and low ash.

Sapric, or humic peats, are the oldest and most decomposed peats, with color ranging from dark brown to black. Normally, sapric peats are the first peats formed in the filling of basins and are the most dense and colloidal. Sapric peats, because of their colloidal nature, take on less water, but retain it more strongly than other peats. Many sapric peats are excellent energy sources and are quite acidic. Sapric, or humus peat, has an average bulk density of about 1,300 pounds per cubic yard.

The von Post scale was developed in Sweden as a field method, or squeeze test, for determining the degree of peat humification or breakdown and is utilized by peat enthusiasts worldwide. According to the von Post method, peats are ranked on a scale from H 1 to H 10 relative to their degree of humification. A von Post of H 1, for example, would represent undecomposed peat that ejects colorless, clear water when squeezed, with the remainder containing easily discernible plant matter. At the opposite end of the scale, at H 10, the peat would be completely decomposed, with no plant remains recognized, and, upon squeezing, the whole amount would come out between one's fingers as a homogeneous material. In general, fibric peat mosses are in the von Post range between H 1 and H 3; hemic reed-sedges, H 4 to H 6; and sapric humus peat, H 7 to H 10.⁴

A typical proximate analysis for peat would yield a moisture content of about

50%; carbon, 26%; oxygen, 16%; hydrogen, 3%; nitrogen, 1%; sulfur, 0.1%; and ash, 4%. Fuel-grade peats may vary between 4,000 British thermal units (Btu's) per pound to as high as 10,000 Btu's per pound depending on moisture content and peat type.

Geology-Resources

In the United States, peat is deposited to some extent in all 50 States. About 25 million acres of peatlands has been identified in the lower 48 States, representing an estimated reserve base of 7 billion tons. Alaska contains an enormous peat resource estimated at 125 million acres. Minnesota, Florida, Michigan, Wisconsin, and Maine, in order of importance, account for the major reserves that are available for commercial harvesting in the 48 contiguous United States. At current mining rates, the U.S. permitted reserve base estimate of 16 million tons could theoretically be depleted within the coming 20 years. (See table 2.)

Although Florida, Maine, Minnesota, and many other States have done a credible job in estimating individual State peat reserves, there has not been a comprehensive effort to consolidate individual State reports to establish the extent of U.S. peat resources since the 1922 U.S. Geological Survey (USGS) publication, "The Occurrence and Uses of Peat in the United States."⁵

As a result of the energy crisis in the mid-1970's, the Department of Energy (DOE) initiated a Peat Resource Estimation project in several States to provide information on the extent of our Nation's availability of peat resources for energy utilization, but the results were incomplete and never fully tabulated.

In the mid-1980's, the University of North Dakota and the U.S. Geological Survey (USGS) submitted a joint proposal to the U.S. Department of the Interior designed to survey the peat resources of the United States. The principal objective of the proposal was to systematically bring together and analyze the information obtained from DOE's Peat Resource Estimation program that had

been conducted by the individual States. Other non-DOE-sponsored research in other States was also to be included. To date, a Federal program has not been established to research and publish a comprehensive report of U.S. peat reserves and resources.

Technology

Mining.—Peat is mined or harvested by numerous methods in the United States dependent upon the prevailing conditions and the type of peat involved.

Sphagnum peat is mined through a combination of milling, aeration, and vacuum harvesting. A wide variety of equipment is required, including light and heavy power equipment; ditching machines to provide drainage; stumper, wood rake, and turner-aerator equipment to clear and aerate the surface; milling machines; vacuum harvesters; and wagons or trucks for transporting the harvested peat to the processing plant.

Reed-sedge peat may be harvested with conventional agricultural disking equipment, wide track bulldozers, and front-end loaders. Alternate methods involve milling or bulldozing, followed by windrowing and product pickup with a force feed loader equipped with a side-loading attachment. Smaller operations sometimes mine humus peat with power shovels, small draglines, and front-end loaders.

Fuel-grade peat, following conventional field preparation methods, is compressed into 4-inch-diameter cylinders with sod harvesting equipment. The cylinders break off at lengths ranging from 8 to 12 inches and drop to the surface for air drying. After windrowing to effect complete drying, the cylinders are picked up by a force feed conveyor loader and discharged into trailers for transport to the powerplant.

Processing.—All peat usually requires screening to remove debris and to produce a desirable marketable product. In state-of-the-art sphagnum operations, harvested peat is fed to a radar screen for sifting and the removal of large debris.

The raw product is next discharged to a double-deck vibrating screen to effect sizing and to remove the smaller debris. Product oversize passing over the primary screens is hammermilled and recycled to the screening process. Processing is effected in a closed system equipped with an overhead vacuum takeoff for fine or dusty material. The fines may be recycled or conveyed to a closed waste bin outside the plant.

Product-grade material is discharged to a surge bin from which peat is processed in a four-step automated turntable process, wherein product is gravity metered into plastic containers, compressed into bales on a 2:1 volume ratio, sealed, and conveyed to storage. Four-cubic-foot bales are the most popular size produced, but 2-cubic-foot and 6-cubic-foot bales are also produced in significant quantities.

Reed-sedge and humus peats are screened, packaged in bags, or sold in bulk. The materials may also be blended with perlite, vermiculite, sand, and sphagnum moss and packaged as potting soils or for a variety of other uses. Peat-sand mixtures are popular bulk materials that are sold to golf courses for greens construction and for top dressing greens, tees, and fairway turf.

Economic Factors

The data of table 3 show the long-term peat price trend for the period 1970-91. Actual prices, without adjustment for inflation, increased at an average annual rate of 5% per year over the 21-year period. Prices expressed in terms of constant 1991 dollars, however, declined at an average annual rate of 2% per year over the same period. The U.S. peat industry has overcome inflationary pressures principally through the rationalization of capacity, together with a move to higher volume modern and efficient plants, the proliferation of value-added consumer products, and through the importation of more peat and finished peat products from Canada. (See table 3.)

ANNUAL REVIEW

Legislation and Government Programs

The U.S. Fish and Wildlife Service continued to act as custodian for the preservation of a 93,000-acre peatlands on the environmentally sensitive Pamlico Peninsula in northeastern North Carolina. About 35 million dry tons of high-energy, fuel-grade peat was deposited to an average depth of 6 feet over 70,000 acres of the property, formerly owned by First Colony Farms.

Fish and Wildlife planned to combine these lands with its adjacent 10,000-acre Pungo National Wildlife Refuge to form Pocosin Lakes National Wildlife Refuge. The development was to include fire control, maintenance of drainage canals, provision of grain for feeding, and enforcement of wild game hunting. Deer, black bear, and wood duck were native to the area.⁶

The Pamlico Peninsula is the site of North Carolina's largest peat reserves. The peninsula is estimated to include 360 square miles of peatlands containing about 210 million tons of peat on a moisture-free basis. Only two small peat operations are currently active on the peninsula.

Large-scale commercial composting programs, fueled by environmental regulation, continued to proliferate in both the public and private sectors during 1991 and competed with peat in selected applications. Compost could lead to further growth in mulching and soil amendment activity dependent upon economic factors and consumer acceptance. In any event, several peat-compost product blends were marketed by major U.S. peat producers in 1991, representing a new trend that will most probably continue to increase in proportion to the availability of quality compost materials.

Issues

Peat deposits along the U.S. Eastern Seaboard, extending from Maine to Florida, are heavily regulated by Federal,

State, and local environmental agencies owing to population density and sensitive wetlands areas; this is also true in California along the U.S. West Coast, and to an extent in several Midwestern and Northeastern States. Conversely, the northern tier Great Lakes States are situated, for the most part, in more environmentally friendly surroundings. This is particularly true in Minnesota, where the prudent development of the State's tremendous peat reserve base—representing about 30% of total reserves in the 48 contiguous United States—is encouraged to generate employment and contribute to economic growth.

Between 1987 and 1990, U.S. domestic peat sales declined 17%, total domestic consumption declined 11%, and 10 U.S. peat operations were closed. During the same period, imports of Canadian peat increased 16%, and the U.S. import reliance rose 9% points, from 35% of total demand in 1987 to a record 44% in 1990.

About one-half of the decline in domestic peat production and demand was in the leading States of Florida and Michigan, but equally disturbing was the fact that one-third of the loss was attributable to 5 States in mid-America (Illinois, Indiana, Iowa, Ohio, and Pennsylvania); New Jersey dropped 9%, and California, Washington, and Georgia, 4% each. Production in California has ceased altogether.

About 30 U.S. peat operations were idled or pressured out of the business between 1987 and 1991. Many producers and consumers felt that a more equitable balance between environmental regulation and peat mining was needed, given the importance of peat to the U.S. economy and its value to the U.S. consumer. Industry sources were becoming increasingly cognizant of the role that Minnesota's tremendous sphagnum peat reserves will play in advancing future competitiveness and growth in the U.S. peat business.

Production

U.S. peat production declined 9% in 1991, according to the U.S. Bureau of Mines annual survey of domestic peat producers in the 48 contiguous United States. The harvest season in the Great Lakes States was restricted because of bad weather. A total of six peat bogs reportedly closed in the States of Georgia, Maryland, Michigan, New Jersey, North Dakota, and Pennsylvania during 1991. Fisons Horticulture, Inc. transferred the jurisdiction of its peat bogs in Minnesota and Iowa to State regulatory agencies. Plans by EcoPeat Co.—a U.S. affiliate of the Finnish firm Outokumpu Oy—to develop 360 megawatts of peat-fueled electrical powerplants in cooperation with south-central Florida utility companies were postponed.

Peat was harvested and processed by 76 operations in 19 contiguous States. The States of Georgia, Maryland, and North Dakota did not report production in 1991. The majority of U.S. peat production, about 80%, was conducted in high-volume operations that accounted for about 30% of the total number of active facilities. Twenty-two peat operations in Florida and Michigan produced about 60% of the U.S. total.

Geographically, about 50% of the total U.S. peat output was from seven contiguous States in the Midwest and north-central Great Lakes region, together with three Western States. Four States in the southeast accounted for about 40% of the total, and five States in the northeast provided 10%. (See tables 4 and 5.)

On a weight basis, reed-sedge peat was 63% of total U.S. production; humus, 21%; sphagnum moss, 6%; hypnum moss, 5%; and other forms, 5%. On a volume basis, reed-sedge was 64% of the total; humus, 16%; sphagnum, 12%; hypnum, 5%; and other forms, 3%.

In Alaska, A&A Services, The Dirt Co., and Landscape Supply Corp. produced peat in the Anchorage area, while Great Northwest, Inc., was active near Fairbanks. Alaskan peat demand increased dramatically during the early-1980's coincident with the economic

boom precipitated by the development of the Alaskan Oil Pipeline. Production peaked at 125,000 cubic yards in 1984 and carried a value of \$859,375 or \$6.88 per yard. The potential for future development of Alaska's tremendous peat resources will be dependent upon Alaska's economic growth, peat's emergence as an effective filtration medium for the control of toxic waste effluents in mining, and logistical factors.

Hyponex Corp. and Michigan Peat Co. are major producers and distributors of peat products in the United States. In 1991, Hyponex harvested and processed reed-sedge peat from facilities in 6 States extending from New Jersey to Colorado. Hyponex markets peat and peat blends throughout much of the United States. Hyponex operates from parent headquarters, the O. M. Scott & Sons Co., in Marysville, Ohio. The O. M. Scott Co. is a recognized leader in the lawn and garden fertilizer market, and the recent acquisition of Hyponex has added a new dimension to the Scotts family of products—a full line of quality organic landscape/garden products and indoor plant care items.

Michigan Peat Co. is a major supplier of retail soil amendments and professional grower horticultural products in the north-central States, providing a wide range of peat-based products to an area containing more than 40% of the Nation's population. Peat is harvested and processed in five locations, including sphagnum moss production at Cromwell, MN, two facilities in the "Thumb" area of Michigan, near Sanilac, together with one operation each in north-central Colorado and Central Florida.

Today, all operations are headquartered in Houston, TX, from which a \$15 million annual business is coordinated. Michigan Peat has the capacity to harvest 150,000 tons of reed-sedge peat and sphagnum peat moss annually, or about 20% of current U.S. production.

Production and sales volume, f.o.b. plant, declined in Minnesota during the year owing to inclement weather. Nine producers were active during the year, of which there were three major sphagnum

producers in Carlton County and St. Louis County and one major bulk producer of reed-sedge in Aitkin County, all near Duluth, MN. Minnesota's premium peat was valued at \$53 per ton or 130% above the U.S. average.

Aitkin Agri-Peat began harvesting and selling reed-sedge at its bog in Aitkin County in 1984. The operation was improved and expanded through the lease and later purchase of specialized equipment from the Natural Resources Research Institute (NRRI), at Duluth. Aitkin also designed and constructed unique harvest machinery that provides an efficient and economical method of harvesting bulk peat. Production capacity is about 20,000 cubic yards annually, from 100 acres of the 300-acre deposit. Aitkin Agri-Peat markets bulk reed-sedge to general contractors and golf courses within a 250-mile radius of the harvest site near McGregor, MN.

Peatrex Ltd. began sphagnum production in 1985 near the town of Cromwell, MN, in Carlton County. The operation is of Finnish design with good drainage. The fields are profiled for fast turnaround after heavy rains. In 1989, Peatrex was purchased by Premier Enterprises of Canada, and since, has constructed a state-of-the-art sphagnum processing facility on the property. Harvested sphagnum from the 250-acre operation is processed into 2-, 4-, and 3/4-cubic-foot bales or sold in bulk.

Minnesota Sphagnum, Inc. (MSI) commenced sphagnum harvesting in 1987. The past 4 years have been devoted to improvements in processing facilities and field expansion. Expansion of this operation will continue for the next 3 to 5 years. MSI currently harvests peat from 250 acres and markets sphagnum peat in bale and bulk in the Midwestern and Southwestern States. The MSI organizational structure is through Hyde Park Products and Conrad Fafard, Inc.

New horticultural peat projects were reported to be under consideration in the States of Georgia, Maine, New Mexico, North Carolina, and North Dakota.

Down East Peat LP was operating a 22.8-megawatt, peat-fired electric

powerplant near Cherryfield, ME. At full capacity, the powerplant will require about 165,000 tons of bone-dry peat annually. Fuel-grade peat was extracted from the adjacent Denbo Heath Bog by a private contractor.

Humates were mined from the San Juan Basin deposits of New Mexico and sold for use as a soil conditioner. In 1985, the last year of available data, humate production was about 23,000 cubic yards, with an f.o.b. mine value of \$404,000. Mining and processing were conducted by three companies in McKinley, Sandoval, and San Juan Counties.

Consumption and Uses

During 1991, the U.S. peat business continued to reflect the general downturn in the U.S. economy that has subsisted since 1989. During this 3-year period of recession, U.S. apparent domestic consumption and sales have not changed significantly. Apparent domestic consumption has held level in the 1.3- to 1.4-million-ton range, and domestic sales volume has held constant at 0.8 million tons.

Domestic bulk and packaged forms, on a weight basis, continued to command equal shares of the market. About 90% of U.S. producer sales was for general soil improvement and horticultural use. In horticulture, peat was used predominately for general soil improvement, as an ingredient in potting soils, and in the nursery business.

In agriculture, peat was used for general soil improvement, in mixed fertilizers, as a carrier and coating agent in seed inoculants, for vegetable cultivation, and as poultry litter. Specialty applications included peat's use in golf course greens construction and course maintenance, as an earthworm culture medium, and for mushroom cultivation. Minor amounts of peat were used as fuel for electric power generation.

The U.S. Department of Agriculture (USDA) reported that the U.S. mushroom industry had just capped a decade of growth, but faces a number of challenges

arising from increasing environmental sensitivity, some uniquely related to the nature of mushroom production. The United States is the world's largest commercial mushroom producer, with 21% of the world's 3.3 billion pounds in 1990. Cash receipts ranked fifth among all vegetables in 1990, with sales totaling \$671 million in 1990-91, nearly doubling over a decade.

One major challenge facing U.S. mushroom growers, according to USDA, arises when compost is substituted for peat as a growing medium. The storage and disposal of used compost can reportedly lead to environmental problems, not just for growers but for their nonfarm neighbors as well.⁷ (See tables 6, 7, and 8.)

Stocks

In 1991, primary producer peat stocks declined 16% to 0.3 million tons, according to the Bureau's annual survey of domestic peat producers. Stocks of peat in all forms were about 50% of production, typical of the industry. Reed-sedge peat accounted for about 63% of total stocks. (See table 9.)

Transportation

Peat was moved predominately by truck in both bulk and packaged form. Small producers were restricted to local market areas because of the sensitivity of peat prices to transportation charges. High-volume producer costs were less sensitive to transportation charges, allowing for interstate movement of peat and peat products.

Markets and Prices

The average price for domestic peat, f.o.b. plant, declined 5% to about \$23 per ton. Packaged and baled peat sold for about \$27.50 per ton, a 10% decline, while bulk peat prices were down about 4% to \$18.50 per ton. Packaged and baled peat were sold at a 48% premium relative to bulk peat. Sphagnum moss sold at a premium \$62 per ton or 170%

above the national average. (See table 10.)

Foreign Trade

In 1991, Canada continued to provide more than 99% of total U.S. peat imports—principally sphagnum moss—and new records were again established for both volume and value. Canadian imports reached a record 631,000 tons, 48% of the total U.S. peat supply, and carried a U.S. Customs value of \$95.7 million, equating to \$152 per ton. The value of Canadian shipments at the U.S. border exceeded total U.S. domestic peat sales, f.o.b. plant, by \$76.5 million or 400%.

The United States accounted for roughly 90% of total Canadian export shipments in 1991. About 70% of the total was shipped from Central and Atlantic Canada, with the remaining 30% from western Canada. Officials of Energy, Mines and Resources Canada in Ottawa, Ontario, said that Canada's improved performance in the United States was attributable in part to a greater visibility brought about by an intensive promotional campaign.⁸ Canada typically exports about 80% of its total peat output. (See table 11.)

Another \$2 to \$3 million in Canadian peat merchandise was recorded by U.S. Customs under the "Articles of Peat" category. Peat pots and other specialty peat-based products, including some peat mixtures, were reportedly included under this category. Although Canadian peat shipments in all forms entered the United States duty free, a tariff of 4.7% was imposed by Canada on U.S. peat. The United States, to date, has not exported peat to any destination, according to U.S. Bureau of the Census data.

Energy, Mines and Resources Canada reported that about 77% of all Canadian shipments in 1991—domestic and export—originated from Quebec and New Brunswick in eastern Canada. Alberta, in western Canada, supplied about 10% of the total. The remaining 13% was reported to originate principally from Manitoba and Saskatchewan in western Canada, with minor contributions from

the eastern Provinces of Newfoundland, Nova Scotia, and Prince Edward Island. (See table 12.)

World Review

Global peat production was estimated to have declined about 6% in 1991, based on news of a continuing downturn in U.S.S.R. agricultural productivity in the midst of significant political and economic restructuring. Production in all other countries was believed to be comparable to 1990 levels. The total value of world peat production, assuming an average f.o.b. plant value of \$20 per ton, was about \$4 billion.

Although peat was known to be deposited in the tropics of Africa, Argentina, Brazil, China, Indonesia, Malaysia, New Zealand, Paraguay, and Uruguay, production data were not available. (See table 13.)

Industry Structure.—The U.S.S.R. accounted for about 90% of global peat production in 1991, followed by Ireland, 4%; Finland, 3%; Germany (Western states) and Sweden, 1%; the United States and Canada, 1%; and all other countries, 1%.

In the U.S.S.R., production was confined to the Baltic Republics, the Moscow-Gor'kiy area, and Belorussia, although peat was known to be deposited throughout much of the country. Peat was burned in thermal powerplants in European U.S.S.R. and was also used to fire industrial boilers and large heating plants.

The use of peat in the U.S.S.R. was reportedly declining because of insufficient reserves in the primary consuming areas and restricted demand in the energy and agricultural sectors owing to a radical shift in sociopolitical and socioeconomic philosophy. The chemical industry produced methanol and synthetic natural gas from peat.⁹

Ireland and Finland, in order of importance, accounted for about 68% of the estimated 19 million tons of peat produced outside the U.S.S.R. in 1991. In Ireland, greater emphasis was being placed on fuel peat technology transfer,

environmental technology, and the marketing of horticultural peat, while in Finland, plans for additional peat-fueled powerplants were under consideration. (See table 14.)

In 1990, Ireland's Bord na Móna produced about 7.5 million tons of peat, well above targeted levels, and record operating profits were achieved. These positive results were a reflection of the success of a major reorganization effected in 1988.¹⁰

Bord na Móna, established by the Turf Development Act of 1946 to develop Ireland's peat resources, sells milled peat to the Electricity Supply Board for use in domestic peat-burning power stations, briquettes and machine turf on the domestic fuel market, moss peat and other growing media in the garden and horticultural industries on a worldwide basis, and manufactures pollution abatement products.

The reorganization in 1988 established four core business divisions. The largest of the new divisions is the Peat Energy Div., which is responsible for milled peat operations, with sales accounting for one-half the group's turnover. Milled peat productivity has been doubled and unit costs dramatically reduced. The division's principal objective was to continue to improve the comparative economics of milled peat relative to oil, gas, and coal.

The Solid Fuels Div.—"briquettes and machine turf"—accounts for about 25% of total sales. The outlook for solid fuels, however, has been clouded by a swing in demand to natural gas by industrial users of solid fuels as an inevitable consequence of the extension of the national gas grid and a significant rise in privately produced turf in the Midlands region, a traditionally strong market area for briquettes. Production of private turf—promoted by the Turf Development Act of 1981—rose to 1.5 million tons in 1990, representing a fourfold increase over that of the past decade. The division anticipates a rationalization of capacity to accommodate the private sector.

The Horticultural Products Div. is a major exporter with more than 90% of

production being sold abroad, mainly to markets in the European Community (EC). A minority holding in a Netherlands cooperative was established in 1990 to enhance the division's presence in what is regarded as Europe's leading market in horticultural products. Effective January 1990, the division established its own distribution subsidiary, Du Móna France S.A., with offices in Lyon. This strategy, together with the previous acquisition of the French horticultural peat subsidiary Pouget Solami, should further enhance the division's competitive advantage in the French peat market.

The United Kingdom is the largest market for the division's exports, and much effort was spent in restructuring marketing strategy to deal with declining disposable income in the United Kingdom and an increasing awareness of environmental considerations on the part of consumers. Bord na Móna reiterated its opposition to the unacceptable practice of exploiting boglands of special scientific interest and continued to transfer environmentally sensitive boglands to the Wildlife Service. Ultimately, 8,400 acres of boglands will be protected in accordance with Government policy.

Peat accounts for about 4% of Finland's present energy supply, but plans were formulated to increase future peat production dramatically as a fuel for electric power generation. Finland's product distribution consists of about 80% milled peat and 20% sod peat. Plans were also formulated to increase the production of peat for horticultural purposes and for industrial and environmental applications. Finland's current production capability is about 6 million annual tons.¹¹

Sweden currently produces about 1 million cubic meters of horticultural peat and about 2 million cubic meters of fuel-grade peat annually. Swedish peatlands cover an area of about 15.6 million acres, or about 15% of the total land area. About 865,000 acres of peatland is available for fuel peat production. The overall area suitable for horticultural peat production has not yet been surveyed.

Sweden has about 50 producers of horticultural peat, mainly in the south and middle regions. Roughly 400,000 cubic meters is produced as milled peat and 600,000 cubic meters as sod peat, of which 30% to 35% is exported. More than one-half of the domestic consumption is used by amateurs for home and garden applications.

After reaching a maximum production and sales of about 2.5 million cubic meters in 1950, fuel peat declined dramatically because of its economic disadvantages to cheaply priced fuel oil. By 1970, fuel peat production in Sweden was nonexistent. There was a subsequent revival in fuel peat demand beginning in the early 1980's, however, as an aftershock of the global energy crises of the 1970's.¹²

Capacity.—The data of table 13 are rated capacity for peat operations as of December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

Current Research

The United States National Committee of the International Peat Society (IPS) hosted the International Peat Symposium in Duluth, MN, August 19-22, 1991, under the title, "Peat and Peatlands: The Resource and Its Utilization." The symposium was organized in cooperation with the Iron Range Resources and Rehabilitation Board (IRRRB) and the Natural Resources Research Institute (NRRI), University of Minnesota, Duluth.¹³

An international contingent of peat scientists and industry representatives heard technical papers on a variety of

subjects in two areas: Commission I—Survey, Classification, Ecology and Conservation of Peatlands, and Commission II—Winning, Harvesting, Storage, Transportation and Processing of Peat and Sapropel for Industrial, Agricultural and Horticultural Purposes. Commission papers were presented by representatives from Canada, China, Finland, Ireland, Sweden, and the United States.

Researchers from NRRI gave presentations under the titles: Oil Sorptive Properties of Several Minnesota Peats;¹⁴ The Physical Characterization of Selected Peat-Based Composts;¹⁵ Peat as an Amendment in Poultry Manure Composting;¹⁶ and, Minnesota Peat Producers, Their Deposits and Products, and a Proposed Standard for Minnesota Peat Products.¹⁷ NRRI scientists reported that the oil absorption and compost products should be commercially feasible in the near future.

STS Consultants, Ltd., Minneapolis, MN, presented a paper entitled, "A Peat/Wetland Treatment Approach to Acidic Mine Drainage Abatement."¹⁸ The firm reported that peat wetlands demonstration plots constructed and operated during the past 2 years had effectively removed 80% to 95% of copper and nickel emanating from acid mine drainage streams. STS is currently constructing the first commercial peat wetlands system in Minnesota. The system will be designed to treat a flow of approximately 10,000 gallons per day, constructed for subsurface flow utilizing 1 foot of limestone as a substrate, covered by about 3 feet of fibrous screenings and peat mixture.

Peat research continued at a heady pace during 1991, and many projects were reaching commercial fruition. Commercial ventures were established to produce and market peat-based oil absorbent products in significant quantities in the United States. Consumers of the peat-based products liked the superior absorbency and environmentally friendly aspects of disposal relative to clay-based products. Peat was also shown to be an effective filtration source for the removal of toxic

wastes from secondary sewage effluents, urban stormwater management control, for the elimination of offensive odors, and as a superior carrier for value-added commodities.

D M S & D Associates, Inc. of Eatontown, NJ, developed and test marketed Sorbital AP, a unique hydrophobic sphagnum peat moss product having superior hydrocarbon absorption properties. The firm reported that 1 pound of the product would effectively absorb 1 gallon of oil typically weighing about 8.2 pounds. D M S & D personnel said that the new product represented an advanced concept in spill cleanup.

The new peat product was reported to be cost efficient and safe to use compared with traditional products. Savings per gallon for the cleanup and disposal of a 1-gallon spill were favorable to traditional clay products, corn-based materials, and paper absorbents, in respective order of magnitude.

In addition to its unique hydrocarbon absorbent properties, the product has disposal advantages. It is biodegradable, fuel blendable, EPA qualified as an alternative fuel with a low ash content, and is vapor suppressive. Thus, the product is environmentally friendly, helping to minimize waste going into diminishing landfills. Its native population of microorganisms assist in bioremediation, and it can be recycled as an alternative fuel. When used on water, it locks in the hydrocarbons, protecting wildlife and reducing environmental impact.

Michigan Peat Co. of Houston, TX, developed a unique compacted peat, Bacctite, that served as a natural potting soil additive, providing improved aeration and drainage. Michigan peat representatives said that Bacctite particle size could be tailored to individual needs, while maintaining its integrity and resistance to breakdown during watering cycles.

Prodex Inc. of Ravenna, OH, continued research into humic acid extracts. The firm developed Biogene products that were sold as agricultural and horticultural plant stimulants, animal feed additives for improved nutrition and

health, and as an accelerator in anaerobic biological sludge digestion in municipal and industrial wastewater treatment. Prodex was developing processes for improved peat fuel and horticultural applications, together with the separation of organic and metal contaminants from industrial wastewater streams.¹⁹

In 1991, several domestic and foreign parties expressed interest in sphagnum moss bioaccumulation processes developed by the U.S. Bureau of Mines Salt Lake City, UT, Research Center that were effective in extracting toxic metal ions from a variety of wastewaters.²⁰ Bureau researchers developed porous polymeric beads, designated BIO-FIX beads, that were prepared by blending sphagnum peat moss or algae into a polymer solution and spraying the mixture into water.

Batch and continuous tests demonstrated that BIO-FIX beads removed arsenic, cadmium, lead, and other toxic metals from acid mine drainage waters collected from several sites. Selectivity for heavy and toxic metal ions over calcium and magnesium was demonstrated. The sorption process was reversible, and metal ions were eluted from the beads using dilute mineral acids. Cyclic tests indicated that the beads continued to extract metal ions after repeated loading-elution cycles.²¹

After 15 years of research, Johnson & Johnson (J&J) launched a new line of ultrathin feminine hygiene napkins in Canada having an absorbent core of processed peat moss. J&J officials said the processed moss could absorb 20 times its weight in liquid. The firm claimed that its peat moss pad provided the same absorbency at one-fifth the thickness of ordinary hygienic pads and was slightly thinner and superior to "ultra thin" pads that relied on superabsorbent polymers.²²

The product, named Sure & Natural Prima, was developed by the company's Montreal-based Canadian unit. Energy, Mines and Resources Canada reported that the equivalent of 500,000 bales of Quebec sphagnum peat moss was consumed in the manufacture of Sure & Natural Prima during 1991.

In Canada, fuel peat projects were under consideration in Alberta, Newfoundland, Nova Scotia, Ontario, and Saskatchewan. Energy, Mines and Resources Canada cited peat as being increasingly perceived as a low-sulfur fuel alternative to coal for power generation.²³

SaskPower and a Meadow Lake company in Saskatchewan planned to build a \$22 million peat-burning powerplant at Jans Bay, north of Meadow Lake. It would reportedly generate 15 megawatts, enough to heat a community of 3,000 homes.

Peat Resources was planning a \$4.5 million pilot plant to produce fuel-grade peat at a prime peatland 35 miles northwest of Thunder Bay, Ontario, Canada. Data collected from the pilot plant operation would be used for the potential design of a \$95 million commercial plant capable of producing 1 million tons per year of peat fuel. The fuel would reportedly be used as an environmentally attractive alternative energy replacement for coal in electrical power generation plants.

The pilot plant would test a process for producing high-grade industrial peat fuel with a heating value comparable to bituminous coal. In a recent test burn completed by Ontario Hydro, the experimental peat fuel produced less than 5% ash, and a mixture of coal and peat fuel reduced sulfur emissions in direct proportion to the quantity of peat blended. Peat Resources, which had been developing the peat fuel process since 1984, applied for a Canadian patent.²⁴

Peat also showed promise as a biodegradable medium in disposable diapers and in food packaging.

OUTLOOK

The history and outlook for peat supply-demand in the United States is shown in table 15. During the past 21 years, U.S. domestic peat production has grown at an average annual rate of about 2.0% per year and apparent domestic consumption by about 3.5%.

The most recent upturn in the U.S. peat supply-demand cycle was experienced between 1981 and 1987. Domestic peat production hit the bottom of the latest cycle in 1981 at 0.7 million tons and gradually increased to a record 1.0 million tons by 1987, representing average annual growth of about 7%. Total apparent domestic consumption during the same period followed the domestic production trend and grew at an average annual rate of 7%, from 1.1 million tons in 1981 to a record 1.5 million tons in 1987.

Between 1987 and 1991, domestic peat production and total apparent domestic consumption have declined 7% and 2%, respectively, owing to a downturn in the U.S. economy. Canadian imports as a percent of the total U.S. supply, however, increased from 35% in 1987 to a record 48% in 1991.

A review of the projections by various members of the U.S. horticultural and community substantiates the existence of a widely held opinion that horticulture will continue as a strong growth industry. The Horticulture Research Institute, National Landscape Association, Society of American Florists, and the National Gardening Association all forecast significant future growth.²⁵

In December 1991, USDA officials were optimistic about future growth in the floriculture and environmental horticultural industry. USDA officials said that the greenhouse and nursery industry business remained on the verge of another wave of expansion. Mr. Doyle C. Johnson, an agricultural economist with USDA, in speaking before the Annual Agricultural Outlook Conference in Washington, DC, stated: "If economic activity accelerates in 1992 and 1993, the outlook will be for double-digit growth for most categories of greenhouse and nursery crops. If the economy continues on its current track, overall sales growth is still expected to range 6% to 8% percent above that of this year. This holds true for producer sales as well as wholesale and retail sales."

The U.S. Bureau of Mines forecast for horticultural peat during the next 5 years

is based on a recovery in the economy and a resultant rebound in domestic production and total apparent domestic consumption. Domestic production of horticultural peat is forecast to grow at an average annual rate of about 5% to levels approaching 0.9 million tons by 1996.

Total apparent domestic consumption for horticultural purposes is forecast to grow at an average annual rate of about 3% per year to about 1.6 million tons by 1996. Canadian imports are forecast to rise by another 110,000 tons by 1996 and to compose 46% of the total U.S. horticultural peat supply. Per capita consumption is forecast to approximate 12.5 pounds by 1996 and might approach the 12.7-pound average experienced during the peak years of 1986 and 1987.

The Bureau's forecast for domestic peat production and demand could be optimistic in the event that Canadian competition becomes more intense, environmental regulations inhibit growth, composting captures an increasing market share, or a continued downturn in the economy persists. On the upside, new uses for peat as a filtration medium for the cleanup of waste streams, oil absorption, composting natural organics, and for hygienic and other purposes could potentially drive U.S. peat demand to levels higher than forecast, regardless of the supply source, domestic or Canadian.

The outlook for growth in domestic fuel peat demand for electric power generation has been deferred beyond the forecast period because of the loss of four 80-megawatt power contracts in Florida to the competitive economics of natural gas. Natural gas is currently in oversupply, and gas prices have declined significantly since last year. Additionally, the capital costs associated with the construction of natural gas powerplants are favorable to peat-based plants.

Florida Power and Light and Florida Power Corp. had previously signed letters of intent with EcoPeat—a U.S. subsidiary of the Finnish firm, Outokumpu—to purchase peat-fueled electrical power from proposed plants adjacent to vast peat reserves to the northwest and southeast of Lake Okeechobee in south Florida. The

plants were to be brought into production sequentially beginning in mid-1995 and, at full capacity, would have required about 2.5 million tons of peat annually, representing a threefold increase in current U.S. peat production.²⁶ (See table 15.)

The global outlook for peat supply-demand is shown in table 16. Last year's outlook for balanced supply-demand conditions, long-range, has been clouded by the continuing downturn in U.S.S.R. production. If the projected downturn only impacts the U.S.S.R.'s internal supply-demand situation, then the world outside the U.S.S.R. should still anticipate reasonably balanced conditions during the next 5 years. If the U.S.S.R. becomes pressured to move surplus product to the international marketplace, however, a global imbalance in peat supply-demand may be precipitated for an indefinite period. (See table 16.)

The U.S. Bureau of Mines basic forecast methodology has been modified to include the assumption that production in the U.S.S.R. will gradually return to 1990 levels by 1996. Otherwise, the former methodology that based global demand on the historic trend in per capita consumption has not changed.

The long-term trend based on the current forecast shows that, between 1991 and 1996, global peat demand is projected to grow at an average 1% per year, about one-half of the projected 2% growth in population. This forecast is consistent with historic trends.

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TABLE 1
SALIENT PEAT STATISTICS

	1987	1988	1989	1990	1991 ^P	
United States:						
Number of active operations	92	88	80	82	76	
Production	thousand short tons	955	844	761	763	697
Sales by producers	do.	958	908	775	795	777
Bulk	do.	499	457	384	397	386
Packaged	do.	459	451	391	398	391
Value of sales	thousands	\$21,020	\$20,320	\$17,703	\$19,200	\$17,887
Average per short ton		\$21.94	\$22.37	\$22.84	\$24.16	\$23.01
Average per short ton, bulk		\$17.72	\$18.14	\$18.98	\$17.76	\$18.52
Average per short ton, packaged or baled		\$26.51	\$26.67	\$26.63	\$30.53	\$27.45
Imports for consumption	thousand short tons	515	590	530	599	632
Consumption, apparent ¹	do.	1,544	1,468	1,336	1,372	1,393
Stocks, December 31: Producers ¹	do.	481	447	402	393	329
World: Production	do.	*208,541	*215,261	*219,502	*196,612	*185,389

^PEstimated. ^RPreliminary. ¹Revised.

¹Apparent consumption equals U.S. primary production plus imports minus exports plus adjustments for industry stock changes.

TABLE 2
WORLD PEAT RESERVES AND
RESERVE BASE

(Million short tons of air-dried peat)

	Reserves ¹	Reserve base ²
North America:		
Canada	24	336,000
United States	16	7,000
Total	40	343,000
Europe:		
Finland	70	7,000
Germany ³	46	500
Ireland	171	900
U.S.S.R.	5,320	160,000
Total	5,607	168,400
Other countries	3	1,600
World total	5,650	513,000

¹Estimated reserves currently under active cultivation or economically recoverable under current market conditions.

²The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).

³Western states.

TABLE 3
TIME-VALUE¹ RELATIONSHIPS
FOR U.S. PEAT

Year	Average annual price, dollars per short ton	
	Actual price	Based on constant 1991 dollars
1970	11.39	37.97
1971	11.69	36.97
1972	11.72	35.34
1973	12.16	34.45
1974	15.56	40.55
1975	16.49	39.21
1976	16.52	36.96
1977	17.25	36.10
1978	17.32	33.61
1979	19.44	34.72
1980	20.54	33.52
1981	24.82	36.81
1982	21.94	30.63
1983	25.73	34.52
1984	24.47	31.46
1985	24.81	30.75
1986	23.11	27.90
1987	21.94	25.67
1988	22.37	25.19
1989	22.84	24.65
1990	24.16	25.04
1991 ^P	23.01	23.01

^PPreliminary.

¹U.S. producer price, f.o.b. plant; average all kinds of peat.

Sources: U.S. Bureau of Mines; Council of Economic Advisors.
Note. The implicit price deflators for 1991 are based on "gross domestic product" and not "gross national product", which was used previously. In addition, the base year is 1987, and not 1982.

TABLE 4
U.S. PEAT PRODUCTION AND SALES BY PRODUCERS IN 1991,
BY STATE

State	Active operations	Production		Sales	
		Quantity (thousand short tons)	Quantity (thousand short tons)	Value ¹ (thousands)	Percent packaged
Colorado	4	W	W	\$396	54
Florida	10	253	244	3,991	15
Illinois	4	W	W	W	98
Indiana	5	22	27	608	72
Iowa	2	W	W	W	67
Maine	2	W	W	W	—
Massachusetts	1	W	W	W	100
Michigan	12	186	249	6,442	77
Minnesota	9	32	36	1,910	44
Montana	2	W	W	W	—
New Jersey	3	W	42	541	98
New York	2	1	1	21	—
North Carolina	1	21	21	W	100
Ohio	3	7	9	222	—
Pennsylvania	7	10	10	207	32
South Carolina	1	W	W	W	85
Washington	3	3	3	W	—
West Virginia	1	W	W	75	—
Wisconsin	4	16	9	227	27
Total ² or average	76	697	777	17,887	50

W Withheld to avoid disclosing company proprietary data; included in "Total or average."

¹Values are f.o.b. producing plant.

²Data may add not add to totals shown because of independent rounding.

TABLE 5
RELATIVE SIZE OF PEAT OPERATIONS IN THE UNITED STATES

Size in short tons per year	Active operations		Production (thousand short tons)	
	1990	1991	1990	1991
25,000 and over	9	9	372	355
15,000 to 24,999	11	10	197	183
10,000 to 14,999	6	4	66	49
5,000 to 9,999	11	7	68	46
2,000 to 4,999	14	14	42	45
1,000 to 1,999	7	7	10	8
Under 1,000	24	25	9	10
Total ¹	82	76	763	697

¹Data may not add to totals shown because of independent rounding.

TABLE 6
U.S. PEAT SALES BY PRODUCERS IN 1991, BY USE

Use	In bulk		In packages		Total ¹	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Earthworm culture medium	2,356	\$48	213	\$4	2,569	\$52
General soil improvement	52,183	1,230	343,632	9,114	395,815	10,343
Golf courses	20,785	481	66	7	20,851	488
Ingredient for potting soils	211,464	3,653	17,593	803	229,057	4,456
Mixed fertilizers	170	12	600	20	770	32
Mushroom beds	6,275	103	—	—	6,275	103
Nurseries	38,620	863	5,656	447	44,276	1,310
Packing flowers, plants, shrubs, etc.	7,279	113	3,218	63	10,497	177
Seed inoculant	1,071	39	1,672	84	2,743	123
Vegetable growing	1,367	34	18,000	—	1,367	34
Other	45,207	589	—	180	63,207	769
Total¹	386,777	7,165	390,650	10,722	777,427	17,887

¹Data may not add to totals shown because of independent rounding.

TABLE 7
U.S. PEAT SALES BY PRODUCERS IN 1991, BY TYPE AND USE

Use	Sphagnum moss			Hypnum moss			Reed-sedge		
	Quantity		Value (thou- sands)	Quantity		Value (thou- sands)	Quantity		Value (thou- sands)
	Weight (short tons)	Volume ¹ (cubic yards)		Weight (short tons)	Volume (cubic yards)		Weight (short tons)	Volume (cubic yards)	
Earthworm culture medium	520	1,040	\$10	255	600	\$12	755	1,255	\$14
General soil improvement	27,148	107,284	2,029	6,630	16,459	460	307,516	664,263	7,328
Golf courses	—	—	—	920	1,900	27	14,208	29,104	278
Ingredient for potting soils	373	1,144	23	20,420	40,900	915	134,998	272,075	2,620
Mixed fertilizers	—	—	—	170	400	12	—	—	—
Mushroom beds	—	—	—	1,275	3,000	45	5,000	9,455	58
Nurseries	9,512	45,259	582	470	1,000	18	32,765	63,130	666
Packing flowers, plants, shrubs, etc.	955	2,377	53	—	—	—	9,242	16,504	121
Seed inoculant	—	—	—	—	—	—	2,743	5,488	123
Vegetable growing	—	—	—	50	100	1	1,139	2,050	29
Other	8,390	27,799	213	379	758	7	1,438	2,875	19
Total²	46,898	184,903	2,910	30,569	65,117	1,496	509,804	1,066,199	11,255
	Humus			Other			Total ²		
	Quantity		Value (thou- sands)	Quantity		Value (thou- sands)	Quantity		Value (thou- sands)
	Weight (short tons)	Volume (cubic yards)		Weight (short tons)	Volume (cubic yards)		Weight (short tons)	Volume (cubic yards)	
Earthworm culture medium	1,039	1,794	\$16	—	—	—	2,569	4,689	\$52
General soil improvement	54,521	86,168	528	—	—	—	395,815	874,174	10,343
Golf courses	5,723	9,466	183	—	—	—	20,851	40,470	488
Ingredient for potting soils	73,266	107,180	898	—	—	—	229,057	421,299	4,456
Mixed fertilizers	600	1,000	20	—	—	—	770	1,400	32
Mushroom beds	—	—	—	—	—	—	6,275	12,455	103
Nurseries	1,529	2,838	44	—	—	—	44,276	112,227	1,310
Packing flowers, plants, shrubs, etc.	300	500	3	—	—	—	10,497	19,381	177
Seed inoculant	—	—	—	—	—	—	2,743	5,488	123
Vegetable growing	178	356	4	—	—	—	1,367	2,506	34
Other	18,000	30,000	180	35,000	35,000	\$350	63,207	96,432	769
Total²	155,156	239,302	1,876	35,000	35,000	350	777,427	1,590,521	17,887

¹Volume of nearly all sphagnum moss was measured after compaction and packaging.

²Data may not add to totals shown because of independent rounding.

TABLE 8
AVERAGE DENSITY OF DOMESTIC PEAT SOLD IN 1991

(Pounds per cubic yard)

	Sphagnum moss	Hypnum moss	Reed-sedge	Humus	Other
Bulk	568	968	1,004	1,393	2,000
Packaged	475	922	922	1,166	—
Bulk and packaged	507	939	956	1,297	2,000

TABLE 9
U.S. PEAT PRODUCTION AND PRODUCERS' YEAREND STOCKS IN 1991, BY KIND

Kind	Active operations	Production (short tons)	Percent of production	Yearend stocks (short tons)
Sphagnum moss	14	42,284	6.1	32,819
Hypnum moss	6	30,800	4.4	1,850
Reed-sedge	37	439,086	63.0	233,054
Humus	21	148,612	21.3	60,341
Other	2	35,879	5.2	500
Total	76	696,661	100.0	328,564

¹Data do not add to total shown because some plants produce multiple kinds of peat.

TABLE 10
PRICES¹ FOR PEAT IN 1991

(Dollars per unit)

	Sphagnum moss	Hypnum moss	Reed-sedge	Humus	Other	Average
Domestic:						
Bulk:						
Per short ton	29.05	31.52	20.61	13.13	10.00	18.52
Per cubic yard	8.25	15.26	10.34	9.14	10.00	10.07
Packaged or baled:						
Per short ton	82.85	59.82	23.24	10.42	—	27.45
Per cubic yard	19.68	27.56	10.71	6.08	—	12.19
Average:						
Per short ton	62.04	48.92	22.08	12.09	10.00	23.01
Per cubic yard	15.74	22.97	10.56	7.84	10.00	11.25
Imported, total, per short ton ²	152.14	XX	XX	XX	XX	152.14

XX Not applicable.

¹Prices are f.o.b. plant.

²Average customs value.

TABLE 11
U.S. IMPORTS FOR CONSUMPTION OF PEAT MOSS, BY COUNTRY¹

Country	1990		1991	
	Quantity (short tons)	Value ² (thou- sands)	Quantity (short tons)	Value ² (thou- sands)
Canada	597,854	\$87,250	630,903	\$95,684
Denmark	238	48	6	5
Ireland	411	85	421	35
United Kingdom	228	75	419	152
Other ³	70	74	96	257
Total⁴	598,802	87,533	631,845	96,132

¹Poultry and fertilizer grade.

²Customs value.

³Includes Australia, Cameroon, Finland, France, the Federal Republic of Germany, Hong Kong, Japan, the Netherlands, Sweden, Switzerland, the U.S.S.R., and the Vatican City.

⁴Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 12
U.S. IMPORTS FOR CONSUMPTION OF PEAT MOSS, BY CUSTOMS DISTRICT¹

Customs district	1990		1991	
	Quantity (short tons)	Value ² (thou- sands)	Quantity (short tons)	Value ² (thou- sands)
Baltimore, MD	20	\$48	—	—
Buffalo, NY	27,742	4,585	40,574	\$6,167
Chicago, IL	146	63	—	—
Detroit, MI	63,587	9,867	71,758	11,441
Duluth, MN	5,074	533	2,378	355
Great Falls, MT	93,485	13,708	95,669	14,136
Laredo, TX	—	—	19	3
Los Angeles, CA	192	31	411	51
Miami, FL	2	5	1	2
New Orleans, LA	—	—	100	230
New York, NY	19	12	6	5
Norfolk, VA	—	—	4	2
Ogdensburg, NY	197,782	27,351	195,183	29,101
Pembina, ND	90,234	14,382	91,792	16,272
Portland, ME	67,029	8,659	71,235	8,907
San Diego, CA	—	—	37	10
San Francisco, CA	—	—	1	2
San Juan, PR	497	109	291	119
Seattle, WA	21,424	3,401	22,964	3,745
St. Albans, VT	31,570	4,780	39,422	5,584
U.S. Virgin Islands	—	—	—	—
Total³	598,802	87,533	631,844	96,132

¹Poultry and fertilizer grade.

²Customs value.

³Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 13
WORLD PEAT ANNUAL PRODUCTION CAPACITY DECEMBER 31, 1991

(Thousand short tons per year)

Country	Rated capacity ¹
North America:	
Canada	820
United States	² 1,000
Total	1,820
Latin America:	
Argentina	5
Europe:	
Denmark	60
Finland	6,000
France	250
Germany, Western states	2,500
Hungary	100
Ireland	8,000
Netherlands	500
Norway	50
Poland	300
Spain	80
Sweden	70
U.S.S.R.	200,000
Total	217,910
Asia: Israel	30
Africa: Burundi	20
Oceania: Australia	20
World total	219,805

¹Includes capacity at operating plants as well as at plants on standby basis.

²Includes rated capacity of 24 idle plants.

Source: Branch of Industrial Minerals, U.S. Bureau of Mines.

TABLE 14
PEAT: WORLD PRODUCTION, BY COUNTRY¹

(Thousand short tons)

Country ²	1987	1988	1989	1990	1991 ³
Argentina: Agricultural use	4	3	3	3	3
Australia ³	10	11	*12	*12	12
Burundi	19	19	16	*13	13
Canada: Agricultural use (shipments)	730	811	*895	*789	*840
Denmark: Agricultural use (sales)	*55	55	*55	*121	110
Finland:					
Agricultural use	*211	*358	*497	*496	496
Fuel	*2,053	*4,133	*5,060	*5,060	5,060
France: Agricultural use*	230	220	220	220	220
Germany: Western states:					
Agricultural use	2,207	*2,340	1,742	*1,653	1,430
Fuel	265	256	256	*262	255
Hungary: Agricultural use*	77	77	77	*70	70
Ireland:					
Agricultural use	285	*332	*293	*253	330
Fuel	6,765	*4,473	*8,557	*7,088	7,380
Israel: Agricultural use*	22	22	22	22	22
Netherlands*	440	330	330	330	330
Norway:*					
Agricultural use	33	33	33	33	33
Fuel	1	1	1	1	1
Poland: Fuel and agricultural use*	275	220	220	220	220
Spain	74	83	83	*77	77
Sweden:*					
Agricultural use	*230	*250	*250	*280	290
Fuel	1,000	1,100	*1,600	1,500	1,500
U.S.S.R.:					
Agricultural use*	180,000	180,000	180,000	165,000	155,000
Fuel	12,600	19,290	18,519	*12,346	11,000
United States:					
Agricultural use	955	844	761	763	*697
Fuel	—	—	—	W	W
Total	*208,541	*215,261	*219,502	*196,612	185,426
Fuel peat included in total	*22,959	*29,473	*34,213	*26,477	25,416

*Estimated. †Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

²Table includes data available through June 15, 1992.

³In addition to the countries listed, Austria, Iceland, and Italy produce negligible amounts of fuel peat and the Eastern states of Germany and Venezuela are major producers, but output is not officially reported, and available information is inadequate for formulation of estimates of output levels.

⁴Excludes data from some States.

⁵Reported figure.

TABLE 15
PEAT U.S. PRODUCTION
AND DEMAND¹

(Thousand short tons)

Year	Primary production ²	Primary demand ³
1970	517	809
1971	605	896
1972	577	917
1973	635	945
1974	731	1,033
1975	772	1,036
1976	774	1,069
1977	781	1,056
1978	822	1,130
1979	825	1,179
1980	785	1,207
1981	686	1,089
1982	798	1,080
1983	704	1,042
1984	800	1,146
1985	839	1,255
1986	912	1,548
1987	955	1,544
1988	844	1,468
1989 ^a	761	1,336
1990 ^b	763	1,372
1991 ^b	696	1,393
1996 ^c	880	1,620

^aPreliminary. ^bRevised.

¹Calendar years.

²Gross production of U.S. peat.

³Apparent domestic consumption; calculated from sum of domestic production and imports, adjusted for yearend stock changes.

^cForecast.

Source: Division of Mineral Commodities, Branch of Industrial Minerals, U.S. Bureau of Mines.

TABLE 16
WORLD PEAT SUPPLY-DEMAND RELATIONSHIPS¹

(Million short tons peat)

	1986 ^r	1987 ^r	1988 ^r	1989 ^r	1990 ^r	1991 ^{r*}	1992 ²	1993 ²	1994 ²	1995 ²	1996 ²
Capacity ³	218.8	218.8	218.8	218.8	219.8	220.0	221.0	221.0	222.0	223.0	224.0
Demand:											
Agricultural	185.6	185.5	185.8	185.3	170.1	160.0	162.6	165.2	167.8	170.4	173.0
Fuel	32.8	23.0	29.5	34.2	26.5	25.4	26.0	26.6	27.2	27.8	28.4
Total	218.4	208.5	215.3	219.5	196.6	185.4	188.6	191.8	195.0	198.2	201.4
Operating rate, ⁴ percent	100	95	98	100	89	84	85	86	87	88	90
Consumption:											
Pounds per capita ⁵	89.1	83.4	84.4	84.4	74.2	68.7	68.6	68.5	68.4	68.3	68.3
Population:											
Billion ⁶	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9

^rEstimated. ^{*}Preliminary. ²Revised.

¹Calendar years.

²Forecast.

³Effective production capability.

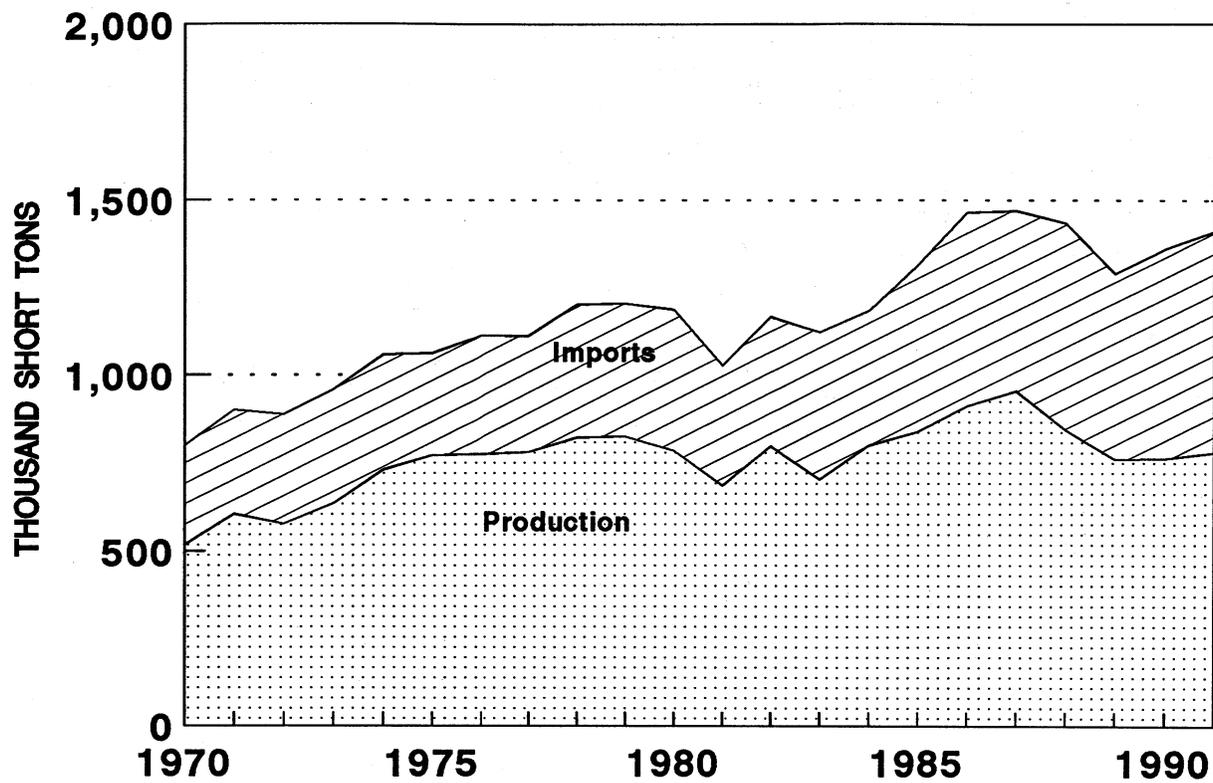
⁴Total demand as a percent of capacity.

⁵Peat demand expressed in pounds per person.

⁶Statistical Abstract of the United States, 1991; Bureau of the Census.

Source: Division of Mineral Commodities, Branch of Industrial Minerals, U.S. Bureau of Mines.

FIGURE 1
PRODUCTION AND IMPORTS OF PEAT IN THE UNITED STATES



PERLITE

By Wallace P. Bolen

Mr. Bolen, a physical scientist, is a graduate of the University of Virginia and has been the commodity specialist for perlite since September 1989. Domestic survey data were prepared by Robin L. Richardson, statistical assistant, and the international production table was prepared by Audrey Wilkes, international coordinator.

U.S. production of processed perlite decreased 11% in quantity and 14% in value, according to the U.S. Bureau of Mines. Expanded perlite sales decreased 6% in quantity but increased 11% in value compared with that of 1990. Construction uses of expanded perlite accounted for 65% of total domestic sales in 1991. (See table 1.)

DOMESTIC DATA COVERAGE

Domestic production data for perlite are developed by the U.S. Bureau of Mines, from two voluntary annual surveys, one for domestic mine operations and the other for expanding plants. All of the mining operations to which a request was sent responded, and all were active. These 10 respondents accounted for 100% of the total processed ore sold and used in table 1. Of the 64 expanding plants canvassed, 62 were active; of these, 48 plants or 77% responded, representing 70% of the total expanded perlite sold or used.

PRODUCTION

Perlite mined for processing came from 9 companies with 10 operations in 6 Western States. New Mexico operations accounted for a large majority of the total tonnage mined. The remaining tonnage came from Arizona, California, Colorado, Idaho, and Nevada. Domestic apparent consumption is defined as production plus imports minus exports. Domestic apparent consumption of processed perlite in 1991 was 595,000 short tons, a decrease of 11% from that of 1990.

Ore producers were Harborlite Corp. and Nord Perlite Co. in Arizona; American Perlite Co. in California; Persolite Products Inc. in Colorado; National Perlite Co. in Idaho; Delamar Perlite Co. in Nevada; and Grefco Inc., Celite Corp. (formerly Manville Products Corp.), and USG Corp. in New Mexico.

The quantity of expanded perlite sold and used from 62 plants in 33 States decreased 6% in quantity compared with that of 1990. However, the value of expanded perlite increased 11% in 1991. The higher value of expanded perlite was mainly attributed to increased usage of higher unit-valued perlite for filler and horticultural applications even though there was decreased consumption of lower unit-valued perlite for construction uses.

Construction-related uses, the major market for expanded material, decreased slightly to 329,100 tons. Expanded perlite used as filter aid, fillers, and in agricultural markets totaled 161,800 tons, a small increase compared with that of 1990. Leading States, in descending order of sales, were Mississippi, Pennsylvania, California, Illinois, Georgia, Virginia, Texas, Kentucky, Florida, Indiana, and Minnesota.

Perlite exports, primarily to Canada, were estimated to be 32,000 tons. Imports of perlite ore, mainly from Greece, decreased slightly to an estimated 60,000 tons compared with those of 1990. (See tables 2, 3, and 4.)

OUTLOOK

Consumption of perlite is directly related to building activity as perlite is used in various building products.

Increased demand is expected as the economy recovers but large, sustained growth in perlite consumption is unlikely. Expanded perlite sold or used in the United States should range between 400,000 and 600,000 tons per year through the middle of this decade.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Mineral Commodity Summaries, annual.
Mineral Industry Surveys, annual.

Other Sources

Chemical Marketing Reporter (newspaper).
Industrial Mineral Magazine (London).

TABLE 1
PERLITE MINED, PROCESSED, EXPANDED, AND SOLD AND USED
BY PRODUCERS IN THE UNITED STATES

(Thousand short tons and thousand dollars)

Year	Perlite mined ¹	Processed perlite				Total quantity sold and used	Expanded perlite		
		Sold to expanders		Used at own plant to make expanded material			Quantity produced	Sold and used	
		Quantity	Value	Quantity	Value			Quantity	Value
1987	778	333	\$10,471	200	\$6,023	533	464	466	\$81,800
1988	830	375	11,588	201	6,064	576	480	479	88,900
1989	722	406	11,426	195	4,875	601	518	517	88,014
1990	726	431	11,101	204	6,342	635	534	527	90,625
1991	839	464	12,144	103	2,942	567	506	498	101,695

¹Revised.

²Crude ore mined and stockpiled for processing.

TABLE 2
EXPANDED PERLITE PRODUCED AND SOLD
AND USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	1990				1991			
	Quantity produced (short tons)	Sold and used			Quantity produced (short tons)	Sold and used		
		Quantity (short tons)	Value (thousands)	Average value per ton ¹		Quantity (short tons)	Value (thousands)	Average value per ton ¹
California	44,900	44,100	\$8,098	\$183	48,900	45,000	\$8,914	\$198
Florida	24,000	23,500	4,910	209	24,200	23,800	5,051	212
Illinois	W	W	W	W	44,500	43,400	9,736	224
Indiana	22,800	22,700	5,947	261	24,000	23,500	4,744	202
Kansas	1,500	1,500	478	317	W	W	W	W
Massachusetts	W	W	W	W	2,200	1,800	703	391
Pennsylvania	50,900	50,700	9,698	191	50,800	50,500	9,568	190
Texas	24,100	23,500	5,592	238	30,100	29,600	7,265	245
Utah	W	W	W	W	4,000	4,000	379	95
Other ²	365,500	360,700	55,904	155	277,100	276,400	55,335	200
Total ³	534,000	527,000	90,625	172	505,800	498,000	101,695	204

W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Average value based on unrounded data and rounded to nearest dollar.

²Includes Alabama, Arizona, Arkansas, Colorado, Georgia, Idaho, Iowa, Kentucky, Louisiana, Maine, Michigan, Minnesota, Mississippi, Missouri, Nevada, New Jersey, New York, North Carolina, Ohio, Oregon, Tennessee, Virginia, Wisconsin, and Wyoming.

³Data may not add to totals shown because of independent rounding.

TABLE 3
EXPANDED PERLITE SOLD AND USED BY PRODUCERS IN THE
UNITED STATES, BY USE

(Short tons)

Use	1990	1991
Concrete aggregate	11,600	14,500
Fillers	26,600	32,100
Filter aid	83,400	76,400
Formed products ¹	292,400	291,200
Horticultural aggregate ²	49,600	53,300
Low-temperature insulation	4,900	5,700
Masonry and cavity-fill insulation	13,300	10,400
Plaster aggregate	10,100	7,300
Other ³	34,700	7,100
Total⁴	527,000	498,000

¹Includes acoustic ceiling tile, pipe insulation, roof insulation board, and unspecified formed products.

²Includes fertilizer carriers.

³Includes fines, high-temperature insulation, oil-water absorbents (1991), paint texturizer, refractories, and various nonspecified industrial uses.

⁴Data may not add to totals shown because of independent rounding.

TABLE 4
PERLITE: WORLD PRODUCTION, BY COUNTRY¹

(Thousand short tons)

Country ²	1987	1988	1989	1990	1991 [*]
Australia ³	6	5	*6	6	6
Czechoslovakia	46	48	*49	*46	44
Greece	230	*233	*240	*243	237
Hungary ³	124	133	120	*103	99
Iran	2	1	2	2	2
Italy [*]	77	77	78	78	77
Japan [*]	83	83	85	85	85
Mexico ³	43	43	41	*47	*53
Philippines [*]	6	8	1	*3	3
Turkey	159	170	158	*165	165
U.S.S.R. [*]	660	660	660	600	660
United States (processed ore sold and used by producers)	533	576	601	639	*567
Total	*1,969	*2,037	*2,041	*2,017	1,998

^{*}Estimated. ^{*}Revised

¹Unless otherwise specified, figures represent processed ore output. Table includes data available through May 19, 1992.

²In addition to the countries listed, Algeria, Bulgaria, China, Iceland, Mozambique, the Republic of South Africa, and Yugoslavia are believed to have produced perlite, but output data are not reported, and available information is inadequate for the formulation of reliable estimates of output levels.

³Crude ore.

^{*}Reported figure.

PHOSPHATE ROCK

By William F. Stowasser

Mr. Stowasser, a physical scientist with 21 years experience, has been the commodity specialist for phosphate rock since 1974. Domestic survey data were prepared by Christopher Lindsay, statistical assistant; and the international data table was prepared by Audrey D. Wilkes, international data assistant.

The historic events of recent years that include the restructuring of the U.S.S.R., the Persian Gulf War, and the significant changes in Eastern Europe will change the demand for phosphate fertilizers. The immediate effect of these events caused a decline in fertilizer consumption, in production, and in trade. In Eastern Europe and the former U.S.S.R., political changes will encourage markets rather than state planning organizations and will determine production and trade patterns in this region. The fertilizer plants and infrastructure in Iraq and Kuwait were damaged by the Gulf War. These events were some of the reasons the world demand and production of phosphate rock declined during the past few years.

World grain stocks increased dramatically in the mid-1980's. The oversupply was caused by a slowdown in the world economy in the early 1980's that lowered the demand for grain. The purchasing power of importing countries was constrained by their debt levels and a strong dollar. In addition, the reputation of the United States as a reliable supplier was damaged by the U.S. embargo on exports to the U.S.S.R. High U.S. price supports stimulated grain production and fertilizer consumption and depressed demand. Finally, weather conditions were favorable for growing from the late 1970's through the mid-1980's.

World grain stocks have dropped markedly since 1986. U.S. Department of Agriculture data show world grain stocks declining from 462 million metric tons in 1986 to 304 million tons in 1991. World grain stocks dropped because of

U.S. supply management policies and unfavorable weather in recent years; U.S. supply management programs idled 60 to 80 million acres per year and caused reduction in grain production and stocks.

World grain consumption has increased steadily over time, reaching an alltime record of 1.74 billion tons in 1991. Grain production reached a record level of 1.77 billion tons in 1991. World fertilizer consumption increased rapidly in the 1960's and 1970's. The increase was from 50 million tons of total nutrients in 1965 to 145 million tons in 1988. World fertilizer consumption has declined since 1988 because of the loss of markets in the U.S.S.R. and Eastern Europe that were not balanced by demand increases from India, China, and North America. World phosphate rock production has declined as the demand for phosphate fertilizers was reduced.

A highlight of the 1990-91 crop year was the increase in diammonium phosphate exports that reached 9.5 million tons, an increase of 5.6% over that of 1990. Exports to India declined in 1991 after the phosphoric acid pricing dispute with Morocco in 1990 was settled. U.S. exports of diammonium phosphate to China increased 30% in crop year 1990-91 to more than compensate for the shortfall to India. The demand for phosphate rock benefited from the record production of 12.9 million tons of diammonium phosphate in the 1990-91 crop year. (See table 1.)

DOMESTIC DATA COVERAGE

Domestic production data for phosphate rock were developed by the U.S. Bureau of Mines from two separate, voluntary surveys of U.S. operations. Of the 16 operations to which a survey request was sent, all responded, representing 100% of the U.S. production data shown in table 1.

BACKGROUND

Phosphate rock deposits occur as marine phosphorites, apatite-rich igneous rock, and modern and ancient guano. All U.S. production was from marine phosphorites. It is the practice of the U.S. industry to express production and reserves in terms of beneficiated product. The grade of the product may be reported as percentage of phosphorus pentoxide (P_2O_5) or as tricalcium phosphate or expressed as percentage bone phosphate of lime (BPL). Conversion factors are: $P_2O_5 = \%BPL \times 0.4576$; $\%BPL = P_2O_5 \times 2.1853$; and $P = P_2O_5 \times 0.436$. The phosphate ore bed or the zone of phosphorus-bearing material is commonly called the matrix in Florida and North Carolina.

Marketable phosphate rock was produced by 16 companies in the United States. Nine companies in Florida and one in North Carolina produced 87% of the phosphate rock. The balance of 13% was produced in Idaho, Montana, Tennessee, and Utah. Approximately 95% of the phosphate rock was used to produce agricultural fertilizers and animal feed supplements. The balance was used in a variety of industrial chemicals.

Sedimentary apatite has a range of chemical compositions. The general formula for marine carbonate-apatite is $\text{Ca}_{10}(\text{PO}_4\text{CO}_3)_6\text{Fe}_{2-3}$. Apatite is host to many cation, anion, and anionic radical substitutions for PO_4 . Accessory elements may be associated minerals or those that are chemical substitutions in the phosphate mineral.

The part of phosphate resources that can be profitably recovered is called reserves. Reserves may increase as new deposits are discovered and as technology is improved. Estimates of phosphate rock reserves are made for a specific date and are subject to changing economic or environmental conditions. Operating companies and companies holding phosphate lands estimate the recoverable tonnages based on current and future economics. Mining plans evolve from this planning. Estimates indicate that about 1 billion tons will be recoverable from the North Carolina deposit and another 1 billion tons will be recoverable from Florida deposits.

The deposits of phosphate rock in Tennessee in the Bigby-Cannon formation are small in size and irregular in shape. They were stripped and mined with 1.5- or 2.3-cubic-meter (2- or 3-cubic-yard) draglines. The ore was trucked or railed to washing and classification plants before agglomerating into electric furnace feed to produce elemental phosphorus. Unfavorable economics caused the suspension of mining phosphate rock in Tennessee in 1991.

The phosphate rock bed of the Pungo River Formation in North Carolina is a primary marine phosphate 6 to 12 meters (20 to 40 feet) thick, overlain with 27 to 40 meters (90 to 130 feet) of sand, clay, and marl overburden. The underlying aquifer was depressurized by pumping water to the surface to ensure a dry pit. Currently, bucket-wheel excavators have replaced dredges to strip the top 12 meters (40 feet) of overburden. Large-capacity draglines with buckets as large as 55 cubic meters (72 cubic yards) were used to strip the remaining overburden and mine the matrix. The matrix was slurried with high-pressure waterjets, pumped to the beneficiation plant,

washed, and classified to produce a minus 16-mesh, plus 200-mesh flotation feed. Flotation concentrate was either calcined or dried.

Most of the phosphate mines in central Florida recover phosphate rock from the Bone Valley Formation. In north Florida, the formation is of equivalent age. Overburden averages about 6 meters (20 feet). The overburden consists of a lay sand and a leach-zone material that overlays the matrix. The materials were selectively strip-mined with large electric draglines. The matrix was slurried in a sump and pumped to the washing plant. Cleaned, screened material from the washer that was plus 14 or 16 mesh was separated and may be a salable pebble product. The minus 16-mesh fraction was deslimed, and the 16-by 150-mesh fraction was floated to produce a concentrate.

Improvement in recovery percentages from phosphate rock deposits in the United States with the introduction of the flotation process occurred in 1927 and 1928. Values in the 14 mesh by 150 mesh became recoverable, adding to the coarser plus 14-mesh pebble fraction. Conversion of phosphate rock to single superphosphate with sulfuric acid was followed by manufacturing high analysis triple superphosphate with phosphoric acid and finally producing the ammonium phosphates by reacting phosphoric acid with anhydrous ammonia. The ammonium phosphates have become the preferred fertilizer for domestic consumption and international trade. At the farm level, advances in the use of mineral-base fertilizers have been made by following recommended application rates, timing and methods of application, using efficient spreaders, and having sufficient material and technical resources. The effect of correct use of mineral fertilizers can double crop yields and minimize the waste of fertilizer.

ANNUAL REVIEW

Legislation and Government Programs

The conversion of phosphate rock to phosphoric acid by acidulation with

sulfuric acid generates about 5 tons of phosphogypsum for each ton of 100% phosphoric acid. Phosphogypsum disposal and control has become a serious problem for the phosphate industry. About 30 million tons of phosphogypsum is produced and stored in stacks in the United States each year. The phosphogypsum, in addition to its large volume, retains some of the radioactive uranium from the host phosphate rock as well as phosphoric acid and other toxic elements. There is concern over leakage of effluent from the stacks into ground water and emissions of radionuclides into the atmosphere. It is understandable that Federal, State, and local governments will have an interest in how phosphogypsum stacks are constructed, operated, and closed. Regulations have been proposed to line new phosphogypsum stacks to prevent ground water contamination and cap completed stacks with a polyethylene sheet and earth cover. The Environmental Protection Agency (EPA) ruled on May 20, 1991, that byproduct phosphogypsum produced from the manufacture of phosphoric acid will be regulated under the more flexible Toxic Substances Control Act (TOSCA). EPA has studied how to regulate phosphogypsum and the associated process wastewater during the past 10 years. Consideration was given to regulating under subtitle C or D of the Resource Conservation and Recovery Act (RCRA). It was concluded that if the hazardous waste C subtitle regulation was implemented, the cost would be sufficiently high to put the industry out of business. If regulated under subtitle D that covered solid wastes, while less onerous than subtitle C, the costs would also jeopardize the financial health of the industry. EPA determined that although the law requires regulation under RCRA and the waste was considered hazardous, it would regulate the industry under TOSCA. TOSCA will allow EPA to regulate on a site-specific and process specific basis. Developing the standard is a process that will take 2 to 3 years.

State and local jurisdictions in Florida studied regulations to control the disposal of phosphogypsum and process

wastewater. Final rules may be less than 1 year away. A consensus appears to have developed from phosphoric acid producers on how to prevent ground water contamination and emissions from stacks. Polyethylene liners and caps probably will be required by Florida regulations.

Strategic Considerations

The 1991 attempted coup in the U.S.S.R. and the dissolution of the Union increased the threat of a Soviet famine over the 1991-92 winters. The Administration extended credit to the U.S.S.R. to ensure some assistance. Technical assistance was advocated; however, large grain shipments from the United States were not expected because U.S. grain stocks were relatively low, the European Community had excess supplies and the political incentive to use them, and the U.S. economy did not encourage massive aid to the dissolving U.S.S.R. Agricultural credits and food aid to the U.S.S.R. did not substantially improve the outlook for fertilizer demand in the United States.

World production of phosphate rock has declined or remained stable since 1989. Production declined again in 1991. World demand for phosphate rock was forecast by the WEFA Group to increase from 155 million tons in 1991 to 178 million tons in the year 2004. The percent changes in demand over this period was forecast to vary from a high of 1.3% to a low of 0.7% per year. Demand for food will drive the demand for phosphate fertilizers and the demand for phosphate rock. The world will become increasingly dependent on the large discovered deposits of phosphate rock and undiscovered deposits in Morocco as other countries deplete their known reserves. The dependency can be modified if technology is developed that will permit recovery of the mineral from leaner deposits and if the cost of recovery will permit recovery of the investment in new mines.

Issues

Mining phosphate rock is an earth-moving exercise. Washing and floating the gangue constituents from the mineral consumes large volumes of water. Processing phosphate rock into phosphoric acid creates phosphogypsum and process wastewater to store and recycle. Runoff from excessive or inefficient application of fertilizer can contaminate ground water and receiving waters. The concern over negative environmental impacts frequently overshadows the understanding of the importance of mineral fertilizers. Without providing and replenishing soil nutrients, production of food to satisfy a world population that will exceed 6 billion by the year 2000 will not be possible. The inevitable increase in world population puts extreme pressure on higher food production by increasing acreage and increasing productivity with fertilizers.

The primary U.S. sources of phosphate rock available for conversion into phosphate fertilizer for domestic consumption and foreign markets are the phosphate mines in central Florida and eastern North Carolina. A number of mines will close in Florida in the 1990's as the deposits are mined out. A tightening of supply does not appear probable as a summation of mining plans of operating companies in the Eastern United States shows that the current level of supply can be maintained through the year 2000. If the supply forecast is correct, pressure to increase phosphate rock prices will not develop, and it will be difficult to justify investment in new mines.

Production

Production of marketable phosphate rock in the United States increased 3.8% in 1991 to 48.1 million tons. This was in close agreement with the 47.7 million tons planned by U.S. producers. Following the closure of Monsanto Co. phosphate rock mines in Tennessee in 1986, Stauffer Chemical Co. and Occidental Chemical Corp. closed their

Tennessee mines and elemental phosphorus furnaces in March of 1991. The economies of producing thermal phosphoric acid were not competitive with purified wet-process phosphoric acid as power costs rose in Tennessee.

Florida and North Carolina.—Phosphate rock was produced in central Florida by Agrico Chemical Co., a division of Freeport-McMoRan Resource Partners L.P.; CF Industries Inc.; and Estech Inc., which closed the Silver City Mine in February 1991 and ended phosphate mining. Phosphate rock also was produced by Gargill Fertilizer, Inc.; IMC Fertilizer Inc. (IMCF); Mobil Mining and Minerals Corp.; U.S. Agri-Chemicals Corp., owned by Sinochem (USA) Inc.; Seminole Fertilizer Corp., owned by Tosco Corp.; and Nu-Gulf Industries Inc., owned by Wingate Creek Acquisition Corp. In northern Florida, Occidental Chemical Agricultural Products Inc. produced phosphate rock for production of phosphoric acid, superphosphoric acid, and diammonium phosphate. In north-central Florida, low-fluorine soft phosphate rock was recovered from hard phosphate rock tailing ponds.

Texasgulf Chemical Co., a division of Texasgulf Inc., a subsidiary of Elf Aquitaine Inc., produced phosphate rock from the Aurora Mine in eastern North Carolina. Dredges were used prior to 1988 to remove the top layer of overburden covering the phosphate ore. The dredges were replaced by bucket-wheel excavating systems in January 1989 to remove the top 12 meters of overburden. Draglines were used to remove the remaining overburden and mine the 10 to 12 meters of matrix.

Western States.—Phosphate rock was mined in Idaho by J. R. Simplot Co., Monsanto, and Rhône-Poulenc Basic Chemicals Co. Simplot produced phosphate rock from the Gay Mine on the Fort Hall Indian Reservation. Mainbed ore was used by Simplot to manufacture phosphoric acid, and the lower grade shale was used in FMC Corp. electric

furnaces in Pocatello, ID. Simplot also produced phosphate rock from the Smoky Canyon Mine in the Caribou National Forest. The concentrate was pumped from the mine to Simplot's fertilizer plant west of Pocatello, ID. Monsanto supplied its electric furnaces in Soda Springs, ID, with phosphate rock from its Enoch Valley Mine in the Caribou National Forest. Rhône-Poulenc produced phosphate rock from the Wooley Valley Mine, Caribou National Forest, ID, and shipped to its electric furnace plant in Silver Bow, MT. Nu-West Industries Inc., a member of the Conda Partnership with Western Coop Fertilizer Co., produced phosphate rock from the Mountain Fuel Mine, Caribou National Forest, ID. The phosphate rock was shipped by rail to Conda, ID, beneficiated, calcined, and used to produce phosphoric acid. Cominco American operated the only underground phosphate rock mine in the United States near Garrison, MT. Chevron Resources Co. produced and concentrated phosphate rock near Vernal, UT. The concentrate was slurried and pumped to Rock Springs, WY. In November, Chevron agreed to sell its phosphate rock mine, the slurry pipelines, and its fertilizer plant at Rock Springs to FS Industries. FS Industries was formed by Simplot and Farmland Industries.

Consumption and Uses

The demand pattern for phosphate rock was similar to that of 1990. In 1991, approximately 94% of the U.S. primary demand was used to manufacture fertilizer, and 6% was used for other applications. Both domestic and foreign markets were supplied by the industry. Of the total demand, 31% was consumed domestically as fertilizer, and 63% was converted to fertilizer and exported. About 5% of the total demand was consumed as phosphorus chemicals domestically, and 1% of the chemicals was exported. The increase in the export of phosphate fertilizers plateaued to new highs in 1990 and 1991. Correspondingly, the export tonnage of phosphate rock declined to 6.2 million

tons in 1990 and 5.5 million tons in 1991. The decline in phosphate rock exports was expected as the availability of high-grade and high-quality phosphate rock in the United States for export was limited and the demand for ammonium phosphates from abroad was strong.

More than 94% of the phosphate rock used domestically was used to manufacture wet-process phosphoric acid, to produce single superphosphate, and triple superphosphate; and the balance was used to produce elemental phosphorus. Production of elemental phosphorus was expected to continue to gradually decline. Rhône-Poulenc started a 72,600-ton-per-year purified wet-process phosphoric acid plant at Geismar, LA, in 1991. The purified acid will be used for food-, pharmaceutical-, and technical-grade phosphates. Rhône-Poulenc's electric furnace plant at Mount Pleasant, TN, was closed. Occidental Chemical also closed its elemental phosphorus plant in Columbia, TN. Olin Corp.'s industrial and detergent phosphate business was acquired by Albright & Wilson Co. Olin closed its purified wet-process phosphoric acid plant in Joliet, IL.

The restructured elemental phosphate industry consists of FMC's electric furnace plant at Pocatello, ID, Monsanto's thermal plant at Soda Springs, ID, and Rhône-Poulenc's two-furnace plant at Silver Bow, MT.

In addition to the electric arc furnaces in the United States, phosphorus furnaces were operated in Canada, France, the Federal Republic of Germany, Italy, Mexico, and the Netherlands. There were 36 electric arc furnaces for smelting phosphate rock in Kazakhstan and an unknown number in Togliatti, U.S.S.R. China, Japan, and India had electric arc furnaces, and there was one furnace in the Republic of South Africa. (See tables 2, 3, and 4.)

Stocks

Phosphate rock stocks were maintained in wet rock piles in Florida and North Carolina and, after drying or calcining, were stored in silos. In the Western

States, phosphate rock was stockpiled during the nonfreezing months of the year near electric furnaces or wet-process phosphoric acid plants to avoid railroad car or truck unloading problems in the wintertime. Phosphate rock inventory levels are of interest to analysts who follow inventory levels to indicate the strength of the demand for phosphate rock. In the United States, ending stocks in 1990 were 8.9 million tons. In 1991, phosphate rock ending stocks were 10.2 million tons, a 15% increase. Stock levels in the United States varied from 8.9 million tons to 10.2 million tons throughout the year. (See tables 5, 6, 7, 8, 9, and 10.)

Transportation

From production centers in central and north Florida, phosphate rock was moved by rail to terminals on Hillsborough Bay, FL, and Jacksonville, FL. In central Florida, CSX Transportation railroad moved phosphate rock to terminals on Hillsborough Bay. The Rockport terminal was owned and operated by the CSX railroad; Port Sutton was owned and operated by IMCF. Eastern Associated Terminal (E.A.T.) was owned and operated by E.A.T., and Big Bend terminals were owned and operated by Agrico Mining Co.

In North Carolina, barges were used to transport phosphate rock from the Aurora Mine to the port at Morehead City for export. Railroad facilities were also available at the Aurora Mine to move phosphate rock to the port or domestic markets. Both railroads and trucks were used in the Western States to move phosphate rock from mines to plants. Two pipelines were used to move slurried phosphate rock from mines to plants. One pipeline was used to pump slurried concentrate from Vernal, UT, to Rock Springs, WY, and another was used to pump phosphate rock from the Smoky Canyon Mine in the Caribou National Forest to Pocatello, ID.

Markets and Prices

The price or value of phosphate rock, f.o.b. mine, was obtained from a semiannual survey of producing companies. The data from the survey were used to develop the weighted average price or value for each grade of phosphate rock sold or used in the domestic market or exported. In the 1950's, the actual selling price of phosphate rock varied from \$5.67 per ton in 1950 to \$6.12 in 1959. In the 1960's, the price varied from \$6.57 in 1960 to \$6.14 in 1969. In 1970, the price was \$5.80 per ton and, in 1974, the average price increased to \$12.04 per ton. The price increased to \$25.00 per ton in 1975 and decreased to \$21.15 in 1976. The abrupt increase in price was initiated by an arbitrary price increase by Morocco's Office Cherifien des Phosphate for exported phosphate rock. Although the actual price declined to \$17.39 per ton in 1977, cost increases caused the price to plateau at more than \$20.00 per ton in 1979; the price peaked again in 1980 to \$22.78 per ton, responding to a strong demand. The price gradually declined to \$19.37 per ton in 1987 and increased to \$23.06 per ton in 1991. Historical average selling prices from 1970 through 1992 are shown in table 12.

Estimates of phosphate rock export prices, unground, f.o.b. vessel, Tampa Range or Jacksonville, FL, by grade were made. Estimates of Moroccan phosphate rock export prices, U.S. dollars per ton, f.a.s. Laayoune, Casablanca, or Jorf Lasfar were made. The price or value of Florida and North Carolina, Tennessee and the Western States, and the U.S. phosphate rock are listed, respectively, by grade for domestic and export markets and average selling prices. (See tables 11, 12, 13, 14, 15, 16, 17, and 18.)

Foreign Trade

Exports of phosphate rock from Florida and North Carolina declined from 14 million tons in 1979 to 5.2 million tons in 1991. Imports of phosphate rock into the United States will probably increase as more phosphoric acid plants on deep water exercise the import option.

Although phosphate rock exports continued to decline, exports of diammonium phosphate reached 9.7 million tons in 1991. The U.S. Department of Commerce reported that diammonium phosphate exports increased from 4.1 million tons in 1986 to 9.7 million tons in 1991. Exports to China increased sharply from 0.5 million tons of diammonium phosphate in 1990 to 5.0 million tons in 1991. Exports to India declined markedly from those of 1990 when it increased diammonium phosphate imports from the United States rather than resolve a price dispute with Morocco.

Exports of diammonium phosphate to destinations other than China and India accounted for 32.7% of U.S. exports. The U.S. industry produced 14.4 million tons of diammonium phosphate and exported two-thirds of this production. (See tables 19, 20, 21, 22, 23, 24, 25, and 26.)

World Review

World phosphate rock production was less in 1991 compared with the peak year 1988. Production from major producing countries has either remained constant or has declined.

It was estimated that world fertilizer consumption declined by 4% in 1991. This was principally caused by reduced consumption in Eastern Europe, the former German Democratic Republic, and the U.S.S.R. The stagnating or declining consumption of phosphate fertilizers in Central and East Europe, in Australia, and a flat demand from developing countries were the principle reasons for a decline in phosphate rock production and trade in 1991.

China increased imports of diammonium phosphate by about 53% in 1991, reaching 2.05 million tons P_2O_5 . India imported a record total of 0.851 million tons P_2O_5 in 1991. Brazil increased phosphoric acid imports in 1991 and increased phosphate rock production. In Western Europe, phosphate rock imports again declined as did imports of processed phosphates. Imports declined to 11 million tons in 1991.

Eastern Europe reduced imports of phosphate rock from Western producers by 38% in 1991 following a 51% decrease in 1990. Imports of phosphate rock from the Kola Peninsula into Central Europe declined 29% in 1990, and it is probable, because of the political changes, imports will again decline.

In the Republic of Russia, production of phosphate rock from Kola is forecast to stabilize at 18 million tons per year. The supply of phosphate rock from the Soviet Republic is decreasing; however, it has no plans to import phosphate rock. Imports of superphosphoric acid were reduced from 700,000 tons P_2O_5 in 1988 to about 500,000 tons in P_2O_5 in 1991.

Moroccan phosphate rock production declined to its 1989 level in 1991. Phosphoric acid exports increased as shipments to India resumed. Diammonium phosphate and triple superphosphate exports from Morocco were unchanged from those of 1990. Western Europe was the principal market for these Moroccan commodities. Tunisian phosphate rock production decreased 6%, and exports decreased 31%. Phosphate rock production and exports from Jordan decreased in 1991 because of the Persian Gulf War.

The world trade talks held under the auspices of the General Agreement on Tariffs and Trade (GATT) reached an impasse when European Commodity negotiators refused to reduce agricultural subsidies. Large agricultural-producing countries, including Argentina, Australia, Brazil, and Chile, have supported U.S. proposals to reduce agricultural subsidies. Other countries, including Austria, Israel, Japan, Mexico, the Republic of Korea, and Switzerland, would benefit from a reduction in subsidies. Scandinavian countries supported the European Community's position. The impasse will not improve the market for increased agricultural exports from the United States.

The U.S. Bureau of Mines estimates of world phosphate rock reserves and the reserve base are shown in tables 28 and 29. Included are reserves and reserve base estimates with costs of less than \$40

and \$100 per ton, respectively. (See tables 27, 28, 29, and 30.)

OUTLOOK

The supply of phosphate rock that is planned to be produced in the United States during the 1990's is listed in table 31. (See table 31.)

The U.S. supply of phosphate rock will be restrained by competition for world markets of manufactured fertilizers and chemicals, by the difficulty of obtaining permits to mine environmentally sensitive deposits, by escalating capital investment and operating costs, and by the inability to develop new beneficiation techniques to efficiently recover the mineral from associated gangue.

The WEFA Group's February 1992 report, "World Demand for Fertilizer Nutrients for Agriculture," emphasized the inevitable population growth that will put pressure on food production. To meet the food needs of the 1990's and beyond, increased fertilizer use will be necessary.

Annual growth rates of world demand for phosphate rock was forecasted by WEFA to vary from 0.7% per year in 1992 to a high of 1.3% per year in the year 2000. The forecast increases in phosphate rock world demand were substantially less than the growth rates in the 1980's.

OTHER SOURCES OF INFORMATION

Fertilizer International.
International Fertilizer Industry Association Ltd.
The British Sulphur Corp. Ltd., Phosphorus and Potassium.
The Fertilizer Institute, Dealer Progress.
The Moroccan Office Cherifien des Phosphates.
The Phosphate Rock Export Association.

TABLE 1
SALIENT PHOSPHATE ROCK STATISTICS

(Thousand metric tons and thousand dollars unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Mine production (crude ore)	148,426	162,299	170,268	151,277	154,485
Marketable production	40,954	45,389	49,817	46,343	48,096
P ₂ O ₅ content	12,470	13,833	15,116	14,172	14,510
Value ¹	\$793,280	\$887,809	\$1,084,022	\$1,075,093	\$1,109,094
Average per metric ton ²	\$19.37	\$19.56	\$21.76	\$23.20	\$23.06
Sold or used by producers ³	43,673	48,441	49,280	49,754	44,707
P ₂ O ₅ content	13,286	14,760	14,935	15,098	13,467
Value ¹	\$845,812	\$947,721	\$1,072,454	\$1,154,422	\$1,030,913
Average per metric ton ^{2 4}	\$19.37	\$19.56	\$21.76	\$23.20	\$23.06
Exports ⁵	8,454	8,092	7,842	6,238	5,082
P ₂ O ₅ content	2,737	2,608	2,522	2,019	1,643
Value ¹	\$194,691	\$206,984	\$227,272	\$191,233	\$167,456
Average per metric ton ²	\$23.03	\$25.58	\$28.98	\$30.66	\$32.00
Imports for consumption	464	676	705	451	552
C.i.f. value	\$22,134	\$26,310	\$29,878	\$21,905	\$28,001
Average per metric ton ⁶	\$47.70	\$38.92	\$42.44	\$48.57	\$50.73
Consumption ⁷	35,683	41,022	42,143	43,967	40,177
Stocks, December 31: Producers	10,884	9,323	11,027	8,912	10,168
World: Production	150,157	161,208	160,032	154,356	*146,859

¹Estimated.

²The total value is based on a weighted value.

³Computer-calculated average value based on the weighted sold or used values.

⁴Includes domestic sales and exports.

⁵Weighted average of sold or used values.

⁶Exports reported to the U.S. Bureau of Mines by companies.

⁷Average unit value obtained from unrounded data.

*Expressed as sold or used plus imports minus exports.

TABLE 2
PRODUCTION OF PHOSPHATE ROCK IN THE UNITED STATES, BY REGION

(Thousand metric tons and thousand dollars)

Region	Mine production		Marketable production						Ending stocks	
	Rock	P ₂ O ₅ content	Used directly		Beneficiated		Totals			
			Rock	P ₂ O ₅ content	Rock	P ₂ O ₅ content	Rock	P ₂ O ₅ content		Value ¹
1990	151,277	17,925	3,653	1,004	42,690	13,168	46,343	14,172	1,075,093	8,912
1991:										
January-June:										
Florida and North Carolina	74,132	8,875	—	—	20,644	6,278	20,644	6,278	476,499	8,030
Idaho, Montana, Tennessee, and Utah	2,994	740	—	—	2,603	758	2,603	758	51,386	1,172
Total	77,126	9,615	—	—	23,247	7,036	23,247	7,036	527,885	9,202
July-December:										
Florida and North Carolina	75,626	11,326	—	—	20,683	6,303	20,683	6,303	524,599	8,192
Idaho, Montana, Tennessee, and Utah	1,733	429	—	—	4,166	1,171	4,166	1,171	56,610	1,976
Total	77,359	11,755	—	—	24,849	7,474	24,849	7,474	581,209	10,168
Grand total	154,485	21,370	—	—	48,096	14,510	48,096	14,510	1,109,094	XX

XX Not applicable.

¹Computer-calculated value based on the weighted sold or used value.

TABLE 3
U.S. PHOSPHATE ROCK SOLD OR USED GRADE DISTRIBUTION PATTERN

Grade (percent BPL ¹ content)	Distribution (percentage)				
	1987	1988	1989 ²	1990	1991
74 or more	3.4	2.0	0.8	0.3	0.2
72 to less than 74	5.4	5.6	7.4	8.3	5.5
70 to less than 72	7.1	8.8	6.2	3.9	6.3
66 to less than 70	61.6	59.7	61.7	59.5	62.9
60 to less than 66	17.5	14.9	19.3	19.8	20.8
Less than 60	5.0	9.0	4.7	8.2	4.3

¹1.0% BPL (bone phosphate of lime or tricalcium phosphate)=0.458% P₂O₅.

²Data do not add to 100% because of independent rounding.

TABLE 4
FLORIDA AND NORTH CAROLINA PHOSPHATE ROCK SOLD OR USED
GRADE DISTRIBUTION PATTERN

Grade (percent BPL ¹ content)	Distribution (percentage)				
	1987	1988	1989	1990	1991
74 or more	3.8	2.3	0.9	0.3	0.2
72 to less than 74	6.0	6.4	7.6	7.6	6.4
70 to less than 72	7.6	8.2	6.2	4.4	5.3
66 to less than 70	65.3	64.0	66.4	63.4	68.6
60 to less than 66	17.3	14.4	18.9	19.3	19.5
Less than 60	(²)	4.7	—	5.0	—

¹1.0% BPL (bone phosphate of lime or tricalcium phosphate)=0.458% P₂O₅.

²Less than 0.1 of 1%.

TABLE 5
TENNESSEE AND WESTERN
STATES PHOSPHATE ROCK SOLD
OR USED GRADE DISTRIBUTION PATTERN

Grade (percent BPL ¹ content)	Distribution (percentage)				
	1987	1988	1989	1990	1991
72 to less than 74	—	—	5.6	13.4	—
70 to less than 72	3.5	12.5	6.1	—	13.6
66 to less than 70	33.9	29.8	28.6	30.7	24.9
60 to less than 66	19.3	18.2	21.8	23.5	28.7
Less than 60	43.3	39.5	37.9	32.4	32.8

¹1.0% BPL (bone phosphate of lime or tricalcium phosphate)=0.458% P₂O₅.

TABLE 6
PHOSPHATE ROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY GRADE AND REGION

(Thousand metric tons and thousand dollars)

Grade (percent BPL ¹ content)	Florida and North Carolina			Tennessee and Western States ²			Total		
	Rock	P ₂ O ₅ content	Value ³	Rock	P ₂ O ₅ content	Value ³	Rock	P ₂ O ₅ content	Value ³
January-June 1990	22,051	6,712	512,676	2,613	755	58,932	24,664	7,467	571,608
July-December 1990	21,825	6,691	520,754	3,265	940	62,060	25,090	7,631	582,814
January-June 1991:									
74 or more	—	—	—	—	—	—	—	—	—
72 to less than 74	1,493	498	45,714	—	—	—	1,493	498	45,714
70 to less than 72	1,010	329	30,590	—	—	—	1,010	329	30,590
66 to less than 70	12,604	3,845	269,147	442	137	14,204	13,046	3,982	283,351
60 to less than 66	3,684	1,038	89,587	606	172	5,285	4,290	1,210	94,872
Below 60	—	—	—	741	187	11,626	741	187	11,626
Total	18,791	5,710	435,038	1,789	496	31,115	20,580	6,206	466,153
July-December 1991:									
74 or more	91	31	3,108	—	—	—	91	31	3,108
72 to less than 74	1,143	382	36,542	—	—	—	1,143	382	36,542
70 to less than 72	1,048	342	33,725	449	148	21,295	1,497	490	55,020
66 to less than 70	14,791	4,520	339,873	521	161	9,498	15,312	4,681	349,371
60 to less than 66	3,684	1,039	88,527	1,181	330	20,464	4,865	1,369	108,991
Below 60	—	—	—	1,219	308	11,728	1,219	308	11,728
Total	22,757	6,314	501,775	3,370	947	62,985	24,127	7,261	564,760

¹1.0% BPL (bone phosphate of lime or tricalcium phosphate)=0.458% P₂O₅.

²Includes Idaho, Montana, and Utah.

³F.o.b. mine.

TABLE 7
PHOSPHATE ROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Thousand metric tons)

Use	1990 total		January-June		July-December		Total	
	Rock	P ₂ O ₅ content						
Domestic: ¹								
Wet-process phosphoric acid	38,409	12,114	16,959	5,077	19,996	5,987	36,925	11,064
Normal superphosphate	2,383	195	34	10	13	4	47	147
Triple superphosphate	429	141	182	60	213	71	395	131
Defluorinated rock	—	—	—	—	—	—	—	—
Direct applications	3	1	—	—	—	—	—	—
Elemental phosphorus	2,256	619	957	266	1,301	349	2,258	615
Ferrophosphorus	36	9	—	—	—	—	—	—
Total	43,516	13,079	18,132	5,413	21,493	6,411	39,625	11,824
Exports ²	6,238	2,019	2,448	793	2,634	850	5,082	1,643
Grand total	49,754	15,098	20,580	6,206	24,127	7,261	44,701	13,467

¹Includes rock converted to products and exported.

²Exports reported to the U.S. Bureau of Mines by companies.

TABLE 8
PHOSPHATE ROCK SOLD OR USED BY PRODUCERS
IN THE UNITED STATES, BY USE AND REGION

(Thousand metric tons)

Use	Florida and North Carolina		Tennessee and Western States ¹		Total	
	Rock	P ₂ O ₅ content	Rock	P ₂ O ₅ content	Rock	P ₂ O ₅ content
1990:	43,876	13,403	5,878	1,695	49,754	15,098
1991:						
January-June:						
Domestic: ²						
Agricultural	16,418	4,939	757	209	17,175	5,148
Industrial	—	—	957	266	957	266
Subtotal	16,418	4,939	1,714	475	18,132	5,414
Exports ^{3 4}	2,373	771	75	21	2,448	792
Total	18,791	5,710	1,789	496	20,580	6,206
July-December:						
Domestic: ²						
Agricultural	18,195	5,486	1,997	516	20,192	6,062
Industrial	—	—	1,301	349	1,301	349
Subtotal	18,195	5,486	3,298	925	21,493	6,411
Exports ^{3 4}	2,562	828	72	22	2,634	850
Total	20,757	6,314	3,370	947	24,127	7,261
Grand total	39,548	12,024	5,159	1,443	44,707	13,467

¹Includes Idaho, Montana, and Utah.

²Includes rock converted to products and exported.

³Exports reported to the U.S. Bureau of Mines by companies.

⁴Total export P₂O₅ content does not equal total on table 1 because of independent rounding.

TABLE 9
FLORIDA AND NORTH CAROLINA PHOSPHATE ROCK SOLD OR USED
BY PRODUCERS

Year	Rock (thousand metric tons)	P ₂ O ₅ content (thousand metric tons)	Value	
			Total ¹ (thousands)	Average per ton f.o.b. mine
1987	38,692	11,891	\$765,061	\$19.77
1988	42,395	13,036	829,963	19.58
1989	43,130	13,185	951,995	22.07
1990	43,876	13,403	1,033,430	23.55
1991	39,548	12,024	936,813	23.69

¹The total value is based on a weighted value.

TABLE 10
**TENNESSEE AND WESTERN STATES¹ PHOSPHATE ROCK SOLD OR
 USED BY PRODUCERS**

Year	Rock (thousand metric tons)	P ₂ O ₅ content (thousand metric tons)	Value	
			Total ² (thousands)	Average per ton f.o.b. mine
1987	4,981	1,395	\$80,751	\$16.21
1988	6,047	1,723	117,758	19.47
1989	6,151	1,752	120,459	19.58
1990	5,878	1,695	120,992	20.58
1991	5,159	1,443	94,100	18.24

¹Includes Idaho, Montana, and Utah.

²The total value is based on a weighted value.

TABLE 11
**MARKETABLE PHOSPHATE
 ROCK YEAREND STOCKS**

(Million metric tons)

Year	Quantity
1982	18.3
1983	14.5
1984	11.9
1985	15.5
1986	13.3
1987	10.9
1988	9.3
1989	11.0
1990	8.9
1991	10.2

TABLE 12
**TIME-PRICE RELATIONSHIPS
 FOR PHOSPHATE ROCK¹**

(Dollars per metric ton)

Year	Actual prices	Based on constant 1990 dollars
1970	5.80	18.16
1971	5.80	17.18
1972	5.62	15.89
1973	6.24	16.58
1974	12.10	29.47
1975	25.35	56.21
1976	21.26	44.31
1977	17.39	33.98
1978	18.56	33.80
1979	20.04	33.53
1980	22.78	34.95
1981	26.63	37.25
1982	25.52	33.56
1983	23.97	30.34
1984	23.99	29.29
1985	24.31	28.83
1986	22.25	25.71
1987	19.37	21.70
1988	19.56	21.20
1989	21.76	22.66
1990	23.20	23.20
1991	23.06	22.25

¹Average annual U.S. producer domestic and export price, f.o.b. mine.

TABLE 13
PHOSPHATE ROCK ESTIMATED EXPORT PRICES¹ PER METRIC TON,
UNGROUND, F.O.B. VESSEL TAMPA RANGE OR JACKSONVILLE, FL,
BY GRADE

Grade (percent BPL ² content)	1988 ³	1989 ⁴	1990 ⁵	1991 ⁶
75	\$33.00	\$38.00	\$41.00	\$41.50
72	31.00	35.50	38.50	38.50
70	28.00	32.00	36.00	36.00
68	26.00	31.00	34.00	34.00

¹Prices include severance taxes, rail freight costs from mine to port, and port loading and weighing charges.

²1.0% BPL (bone phosphate of lime or tricalcium phosphate)=0.458% P₂O₅.

³Estimated selling price, including a revised severance tax of \$1.99.

⁴Estimated selling price, including a revised severance tax of \$1.48.

⁵Estimated selling price, including a revised severance tax of \$1.52.

⁶Estimated selling price, including \$1.68 severance tax.

Source: Phosphate Rock Export Association.

TABLE 14
MOROCCAN PHOSPHATE ROCK EXPORT PRICES, U.S. DOLLARS
PER METRIC TON, F.A.S. CASABLANCA, BY GRADE

Grade (percent BPL ¹ content)	1986	1987	1988	1989	1990	1991*
Khouribga:						
72 to 73	40.50	35.00	40.50	45.00	48.00	49.00
70 to 71	39.00	34.00	38.50	42.00	45.00	45.00
Youssoufia:						
74 to 75	40.50	39.50	45.00	49.00	51.00	49.00
68 to 69	30.50	30.00	34.00	37.00	40.00	40.00
Phosboucraa:						
79 to 80	42.00	40.50	45.50	50.50	53.00	54.00

*Estimated.

¹1.0% BPL (bone phosphate of lime or tricalcium phosphate)=0.458% P₂O₅.

Source: Phosphate Rock Export Association.

TABLE 15
PRICE OR VALUE OF FLORIDA AND NORTH CAROLINA PHOSPHATE
ROCK, BY GRADE

(Dollars per metric ton, f.o.b. mine)

Grade (percent BPL ¹ content)	1990			1991		
	Domestic	Export	Average	Domestic	Export	Average
74 or more	31.84	40.77	39.25	22.27	38.39	34.25
72 to less than 74	27.83	32.17	30.78	28.19	33.66	31.22
70 to less than 72	26.12	30.95	30.56	31.20	31.29	31.28
66 to less than 70	21.39	29.25	21.88	21.69	30.17	22.18
60 to less than 66	22.91	13.19	22.65	24.86	—	24.86
Less than 60	30.18	—	30.18	—	—	—
Weighted average	22.44	30.43	23.55	22.67	31.69	23.69

¹1.0% BPL (bone phosphate of lime or tricalcium phosphate)=0.458% P₂O₅.

TABLE 16
PRICE OR VALUE OF TENNESSEE AND WESTERN STATES¹
PHOSPHATE ROCK, BY GRADE

(Dollars per metric ton, f.o.b. mine)

Grade (percent BPL ² content)	1990			1991		
	Domestic	Export	Average	Domestic	Export	Average
72 to less than 74	35.85	—	35.85	—	—	—
70 to less than 72	—	—	—	37.22	—	37.27
66 to less than 70	24.62	42.47	25.19	20.67	42.67	22.75
60 to less than 66	7.31	41.67	15.95	11.91	—	11.91
Less than 60	13.29	—	13.29	12.54	—	12.54
Weighted average	18.44	42.05	20.58	17.65	42.67	18.24

¹Includes Idaho, Montana, and Utah.

²1.0% BPL (bone phosphate of lime or tricalcium phosphate)=0.458% P₂O₅.

TABLE 17
PRICE OR VALUE OF U.S PHOSPHATE ROCK, BY GRADE

(Dollars per metric ton, f.o.b. mine)

Grade (percent BPL ¹ content)	1990			1991		
	Domestic	Export	Average	Domestic	Export	Average
74 or more	31.84	40.77	39.25	22.27	38.39	34.25
72 to less than 74	31.23	32.17	31.75	28.19	33.66	31.22
70 to less than 72	26.12	30.95	30.56	35.86	31.24	32.95
66 to less than 70	21.59	29.67	22.08	21.63	31.18	22.21
60 to less than 66	20.76	19.42	21.71	22.51	—	22.51
Less than 60	22.31	—	22.31	12.54	—	12.54
Weighted average	21.91	30.66	23.20	21.95	32.00	23.06

¹1.0% BPL (bone phosphate of lime or tricalcium phosphate)=0.458% P₂O₅.

TABLE 18
U.S. EXPORTS OF GROUND PHOSPHATE ROCK, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 2510.20.0000)

Country	1990		1991	
	Quantity	Value	Quantity	Value
Australia	5		—	
Canada	126		151	
France	473		—	
Germany, Federal Republic of	47		—	
India	25		1	
Korea, Republic of	1	NA	—	NA
Mexico	65		1	
Netherlands	144		—	
New Zealand	130		20	
Romania	42		40	
Other	26		6	
Total	1,084	38,695	219	13,078

NA Not available.

Source: Bureau of the Census.

TABLE 19
U.S. EXPORTS OF UNGROUND PHOSPHATE ROCK, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 2510.10.0000)

Country	1990		1991	
	Quantity	Value	Quantity	Value
Australia	64		96	
Austria	104		117	
Belgium-Luxembourg	412		199	
Brazil	57		3	
Canada	341		171	
Finland	21		—	
France	147		644	
Germany, Federal Republic of	291		322	
India	378		615	
Italy	102		66	
Japan	688	NA	643	NA
Korea, Republic of	1,275		982	
Mexico	798		689	
Netherlands	763		643	
New Zealand	46		103	
Poland	29		—	
Romania	42		22	
Sweden	209		103	
Other	108		112	
Total	5,875	215,409	5,530	246,755

NA Not available.

Source: Bureau of the Census.

TABLE 20
U.S. EXPORTS OF SUPERPHOSPHATES, MORE THAN 40% P₂O₅, BY
COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 3103.10.0020)

Country	1990		1991	
	Quantity	Value ¹	Quantity	Value ¹
Argentina	9		12	
Australia	155		159	
Bangladesh	50		281	
Brazil	41		172	
Canada	14		19	
Chile	131		157	
Colombia	8		8	
Costa Rica	9	NA	28	NA
Czechoslovakia	6		—	
Dominican Republic	2		—	
Germany, Federal Republic of	51		—	
Japan	48		37	
Peru	—		8	
Uruguay	13		7	
Other	177		23	
Total	714	95,786	911	120,809

NA Not available.

¹All values f.a.s.

Source: Bureau of the Census.

TABLE 21
U.S. EXPORTS OF SUPERPHOSPHATES, LESS THAN 40% P₂O₅, BY
COUNTRY

(HTS No. 3103.10.0010)

Country	1990		1991	
	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)
Argentina	3,390		—	
Canada	17,322		25,075	
Ecuador	5,498	NA	4,007	NA
Spain	2,598		—	
Other	3,864		5,452	
Total	32,672	\$4,844	34,534	\$5,180

NA Not available.

¹All values f.a.s.

Source: Bureau of the Census.

TABLE 22
U.S. EXPORTS OF DIAMMONIUM PHOSPHATES, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 3105.30.0000)

Country	1990		1991	
	Quantity	Value ¹	Quantity	Value ¹
Argentina	74		112	
Australia	318		345	
Belgium-Luxembourg	361		301	
Brazil	32		30	
Canada	185		232	
Chile	63		49	
China	2,778		5,014	
Colombia	131		117	
Costa Rica	23		19	
Dominican Republic	34		51	
Ecuador	16		24	
France	25		49	
Germany, Federal Republic of	89		61	
Guatemala	2		17	
India	1,345	NA	1,541	NA
Iran	248		—	
Ireland	19		41	
Italy	20		32	
Japan	457		442	
Kenya	81		44	
Mexico	25		(²)	
New Zealand	48		46	
Pakistan	544		611	
Peru	11		19	
Spain	91		37	
Thailand	38		61	
Turkey	401		208	
Uruguay	—		22	
Venezuela	47		—	
Yugoslavia	10		18	
Other	240		192	
Total	7,756	1,278,559	9,735	1,707,088

NA Not available.

¹All values f.a.s.

²Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 23
U.S. EXPORTS OF MONOAMMONIUM PHOSPHATES, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 3105.40.0000)

Country	1990		1991	
	Quantity	Value ¹	Quantity	Value ¹
Argentina	8		14	
Australia	130		144	
Brazil	53		79	
Canada	248		211	
Chile	15		25	
China	—		17	
Colombia	49		50	
Costa Rica	(²)		7	
Dominican Republic	(²)		2	
Ecuador	1		3	
Guatemala	29		18	
Ireland	5	NA	—	NA
Italy	20		19	
Japan	93		109	
Mexico	5		9	
New Zealand	9		—	
Peru	(²)		(²)	
Saudi Arabia	26		30	
Spain	3		(²)	
Thailand	9		11	
Venezuela	21		(²)	
Other	13		22	
Total	737	135,660	770	140,838

NA Not available.

¹All values f.a.s.

²Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 24
U.S. EXPORTS OF PHOSPHORIC ACID, LESS THAN 65% P₂O₅, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 2809.20.0010)

Country	1990		1991	
	Quantity	Value ¹	Quantity	Value ¹
Australia	43		14	
Canada	3		10	
Colombia	5		2	
India	330	NA	246	NA
Indonesia	69		45	
Japan	—		(²)	
Venezuela	58		57	
Other	47		66	
Total	555	95,881	440	76,342

NA Not available.

¹All values f.a.s.

²Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 25
U.S. EXPORTS OF ELEMENTAL PHOSPHORUS, BY COUNTRY

(HTS No. 2804.70.0000)

Country	1990		1991	
	Quantity (metric tons)	Value ¹ (thousands)	Quantity (metric tons)	Value ¹ (thousands)
Brazil	450	\$985	529	\$1,115
Canada	1,470	1,850	1,425	1,944
Japan	9,802	17,269	9,676	17,365
Korea, Republic of	400	636	104	569
Mexico	5,441	8,300	4,384	6,991
Netherlands	—	—	6	41
Taiwan	16	21	121	154
Other	337	559	773	2,242
Total	17,916	29,620	17,018	30,421

¹All values f.a.s.

Source: Bureau of the Census.

TABLE 26
U.S. IMPORTS FOR CONSUMPTION OF PHOSPHATE ROCK AND PHOSPHATIC MATERIALS

(Thousand metric tons and thousand dollars)

Phosphatic materials	HTS No. ¹	1990		1991	
		Quantity	Value ²	Quantity	Value ²
Natural calcium ³ phosphates unground	2510.10.0000	451	21,905	550	27,657
Natural calcium ³ phosphates ground	2510.20.0000	(*)	163	2	344
Dicalcium phosphate	2835.25.0000	2	2,744	2	2,620
Phosphorus	2804.70.0000	10	17,532	9	17,152
Normal superphosphate	3103.10.0010	1	361	1	140
Triple superphosphate	3103.10.0020	(*)	14	(*)	3
Diammonium phosphate	3105.30.0000	11	3,271	7	2,129
Fertilizer containing nitrates and phosphates	3105.51.0000	2	322	2	364
Phosphoric acid	2809.20.0010	(*)	53	1	211

¹Harmonized tariff schedule of the United States.

²Declared c.i.f. values.

³Excludes reported imports from Canada and Israel.

⁴Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 27
WORLD PHOSPHATE ROCK
ANNUAL PRODUCTION
CAPACITY, DECEMBER 31, 1991,
RATED CAPACITY¹

(Million metric tons per year)

Country	Capacity
North America:	
Mexico	1.0
United States	55.0
Total	56.0
South America	10.0
Europe:	
U.S.S.R.	36.0
Other	1.0
Total	37.0
Africa:	
Algeria	2.3
Morocco/Sahara	32.0
Senegal	2.1
South Africa, Republic of	4.7
Togo	3.2
Tunisia	10.0
Other	1.2
Total	55.5
Asia:	
China	19.0
Israel	4.0
Jordan	8.0
North Korea	1.0
Vietnam	1.0
Other	1.0
Total	34.0
Oceania:	
Australia	1.0
Nauru	2.0
Total	3.0
World total	195.5

¹Includes capacities of operating plants as well as plants on standby basis.

TABLE 28
U.S. PHOSPHATE ROCK
RESERVE AND RESERVE BASE
ESTIMATES

(Million metric tons)

State	Reserves ¹	Reserve base ²
Florida	750	2,540
Idaho	90	160
Montana	1	1
North Carolina	390	790
Tennessee	6	10
Utah	—	730
Wyoming	—	210
Total³	1,237	4,441

¹Phosphate rock reserves at a cost less than \$40 per ton f.o.b. mine. Costs include capital, operating expenses, taxes, royalties (if applicable), miscellaneous costs, and a 15% rate of return on investments. Costs and resources are as of Jan. 1991, f.o.b. mine.

²Reserve base at a cost less than \$100 per ton f.o.b. mine. Costs are as defined in footnote 1.

³Data may not add to totals shown because of independent rounding.

TABLE 29
WORLD PHOSPHATE ROCK RESERVE AND RESERVE BASE

(Million metric tons)

	Number of deposits	Reserves ¹	Reserve base ²
North America:			
Canada	1	50	50
Mexico	2	10	110
United States	94	1,230	4,440
Total	97	1,290	4,600
South America:			
Brazil	11	330	370
Colombia	1	—	100
Peru	1	310	310
Venezuela	1	—	10
Total	14	640	790
Europe:			
Finland	1	—	70
Turkey	1	30	30
U.S.S.R.	11	1,330	1,330
Total	13	1,360	1,430
Africa:			
Algeria	1	240	240
Egypt	5	—	760
Morocco	10	4,950	20,490
Western Sahara	1	950	950
Senegal	2	—	160
South Africa, Republic of	1	2,530	2,530
Togo	12	—	60
Tunisia	11	—	270
Total	43	8,670	25,460
Asia:			
China	6	210	210
Christmas Island	1	10	10
Israel	4	—	180
Jordan	3	90	480
Syria	2	190	190
Other	6	30	330
Total	22	530	1,400
Oceania:			
Australia	5	90	590
Nauru	1	5	5
Total	6	95	595
World total	195	12,585	34,275

¹Phosphate rock reserves at a cost less than \$40 per ton f.o.b. mine. Costs include capital, operating taxes, royalties (if applicable), miscellaneous costs and a 15% rate of return on investment. Costs and resources are as of Jan. 1991, f.o.b. mine.

²Reserve base at a cost less than \$100 per ton. Costs are as defined in footnote 1.

TABLE 30
PHOSPHATE ROCK, BASIC SLAG AND GUANO: WORLD PRODUCTION, BY COUNTRY¹

(Thousand metric tons)

Commodity and country ²	Gross weight					P ₂ O ₅ Content				
	1987	1988	1989	1990	1991 ^a	1987	1988	1989	1990	1991 ^a
Phosphate rock:										
Algeria	1,073	1,332	1,223	¹ 1,128	1,090	³ 336	⁴ 404	³ 71	¹ 333	322
Australia	11	13	8	¹ 16	4	2	2	1	³	1
Brazil	4,777	4,672	3,655	2,968	³ 3,309	1,694	1,653	1,293	1,051	1,200
Chile	10	9	14	¹ 14	14	¹	¹	¹	¹	1
China ^a	¹ 15,000	¹ 17,000	¹ 18,500	¹ 19,000	20,000	⁴ 4,470	⁵ 4,470	⁶ 6,000	⁶ 6,200	6,500
Christmas Island (Indian Ocean)	842	—	—	—	—	² 95	—	—	—	—
Colombia	³ 4	35	31	37	35	⁸	⁹	⁸	⁸	8
Egypt	1,167	1,146	1,347	¹ 1,143	1,100	³ 12	² 93	³ 37	¹ 268	275
Finland	553	584	580	546	500	195	215	² 14	201	184
India	679	739	704	⁶ 59	580	226	246	235	² 20	195
Indonesia	3	1	11	2	3	1	(^c)	4	1	2
Iraq ^{a, 5}	¹ 1,100	¹ 1,270	¹ 1,140	⁹ 00	400	330	³ 80	³ 40	² 70	120
Israel	3,798	3,479	3,922	3,516	3,370	¹ 1,214	¹ 1,092	¹ 1,231	¹ 1,104	1,070
Jordan	6,800	6,611	6,900	5,925	4,000	² 2,260	² 1,82	² 2,277	1,945	1,280
Korea, North ^a	500	500	500	500	500	160	160	160	160	160
Mali	8	10	10	¹ 0	10	²	²	²	²	2
Mexico ⁶	689	835	655	⁶ 23	⁵ 95	207	251	197	¹ 174	180
Morocco ⁷	21,300	25,015	18,067	21,396	³ 17,900	⁶ 8,816	⁸ 8,061	⁵ 7,81	⁶ 9,06	5,700
Nauru	1,376	1,540	1,181	926	530	⁵ 30	⁵ 93	⁴ 55	³ 55	200
Pakistan ^a	32	35	40	⁴ 2	25	10	11	13	¹ 4	8
Peru	61	¹ 15	¹ 13	¹ 20	20	20	³ 4	¹ 4	¹ 6	6
Philippines	⁸	8	4	³	3	²	²	²	¹	1
Senegal ⁸	1,874	2,326	2,273	2,147	1,700	⁶ 80	831	823	777	612
South Africa, Republic of	2,623	2,850	2,963	3,165	³ 3,050	⁹ 50	1,079	1,111	1,190	1,100
Sri Lanka	21	23	24	33	30	⁷	⁷	⁸	¹ 1	10
Sweden	221	142	71	⁷	—	82	52	26	³	—
Syria	1,986	2,342	² 256	¹ 1,633	1,415	606	715	⁶ 90	⁵ 11	425
Tanzania	18	15	18	² 5	25	⁵	4	5	⁷	7
Thailand	5	8	7	10	10	2	²	2	³	3
Togo	2,644	3,464	3,355	2,314	2,965	⁹ 60	¹ 1,257	¹ 1,208	⁸ 40	1,076
Tunisia	6,390	6,103	6,610	6,259	6,000	¹ 1,836	1,813	¹ 1,897	¹ 1,815	1,734
Turkey	19	74	85	87	90	⁶	23	26	27	28
U.S.S.R. ^a	34,100	34,400	34,400	33,500	30,000	10,750	10,850	10,850	10,200	9,200
United States	40,954	45,389	⁴ 9,817	46,343	⁴ 8,096	¹ 2,470	13,833	¹ 5,116	¹ 4,172	³ 14,501
Venezuela	99	—	237	165	165	28	—	57	34	34
Vietnam ^a	300	330	500	274	275	105	115	175	96	96
Zimbabwe, concentrate	155	125	134	¹ 148	140	⁵ 4	44	47	⁵ 2	49
Total	¹150,157	¹161,208	¹160,032	¹154,356	146,859	⁴7,296	⁵1,282	⁵0,596	⁴8,628	45,968
Basic (Thomas converter) slag:										
Argentina	(^c)	^a (^c)	(^c)	^a (^c)	(^c)	^a (^c)	^a (^c)	^a (^c)	^a (^c)	(^c)
Belgium ^a	175	170	165	160	160	32	31	30	30	30
Egypt ^a	8	8	8	8	8	2	2	2	2	2

See footnotes at end of table.

TABLE 30—Continued
PHOSPHATE ROCK, BASIC SLAG AND GUANO: WORLD PRODUCTION, BY COUNTRY¹

(Thousand metric tons)

Commodity and country ²	Gross weight					P ₂ O ₅ Content				
	1987	1988	1989	1990	1991 [*]	1987	1988	1989	1990	1991 [*]
Basic (Thomas converter) slag— Continued:										
France	768	775	701	*700	700	138	140	126	*125	125
Germany, Federal Republic of: Western states	*300	*250	*200	*100	—	*50	*45	*30	*19	—
Luxembourg	542	664	680	600	600	98	120	122	*108	108
Total	1,793	1,867	*1,754	*1,568	1,468	320	338	*310	*284	265
Guano:										
Chile	6	4	3	2	2	*1	* (*)	* (*)	* (*)	(*)
Philippines	*1	1	48	*1	1	* (*)	* (*)	16	* (*)	(*)
Seychelles Islands ⁴	5	5	5	5	5	2	2	2	2	2
Total	12	10	56	*8	8	3	2	18	*2	2

*Estimated. Revised.

¹Table includes data available through May 19, 1992. Data for major phosphate rock-producing countries derived in part from the International Fertilizer Industry Association; other figures are from official country sources where available.

²In addition to the countries listed, Belgium and Uganda may have produced small quantities of phosphate rock and Namibia may have produced small quantities of guano, but output is not officially reported, and available information is inadequate for formulation of reliable estimates of output levels.

³Reported figure.

⁴Less than 1/2 unit.

⁵Beneficiated.

⁶Includes only output used to manufacture fertilizers.

⁷Production from Western Sahara area included with Morocco.

⁸Does not include aluminum phosphate production, gross weight, in thousand tons: 1987-191; 1988-119; 1989-140 (estimated, revised); 1990-127 (estimated, revised); and 1991-130 (estimated).

TABLE 31
**PHOSPHATE ROCK PLANNED
 PRODUCTION**

Year	Florida and North Carolina	Idaho, Montana, and Utah	U.S. total
1992	41.5	5.2	47.7
1993	41.5	6.8	48.3
1994	36.5	6.8	48.8
1995	33.7	6.8	46.0
1996	44.2	5.8	50.0
1997	39.9	5.8	45.7
1998	41.2	5.8	47.0
1999	41.2	5.8	47.0
2000	48.1	5.8	53.9

PLATINUM-GROUP METALS

By J. Roger Loebenstein

Mr. Loebenstein, a physical scientist with 17 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for platinum-group metals for 11 years. Domestic survey data were prepared by Evangeline Hemphill, mineral data assistant; and international data tables were prepared by Harold Willis, international data coordinator.

The platinum-group metals (PGM) are composed of six closely related metals: platinum, palladium, rhodium, ruthenium, iridium, and osmium. They commonly occur together in nature and are among the scarcest of the metallic elements. In terms of commercial importance, platinum and palladium are the two most important metals of the group. All of the metals are valued for their corrosion resistance and catalytic activity.

Johnson-Matthey PLC, United Kingdom, reported that Soviet sales of platinum reached an alltime high of 34 metric tons in 1991. In the previous year, Soviet platinum sales were 22 metric tons, and in 1989, they were only 17 metric tons.

Demand for PGM in the United States declined as automotive vehicle production fell to its lowest level in 10 years. This decline was offset by an increase in demand for new cars carrying catalysts in Western Europe in anticipation of European Community legislation that requires all new models introduced after July 1, 1992, to have emissions controls.

DOMESTIC DATA COVERAGE

Domestic production data for PGM are developed by the U.S. Bureau of Mines from a voluntary survey of U.S. refiners. Of the 18 refiners to which a survey request was sent, 8 responded. These represent 44% of the total refined metal production shown in tables 5 and 6. Production for nonrespondents was estimated using prior-year levels adjusted for general industry trends.

BACKGROUND

Products for Trade and Industry

The basic forms of PGM are sponge or powder, which may be converted to other forms such as bars, pastes, or chemicals. The industry employs an extensive number of homogenous and heterogeneous catalysts containing PGM. A typical PGM catalyst may consist of a platinum-rhodium gauze woven from wire. The electronics industry purchases PGM pastes, and the dental industry uses wire and a variety of alloys.

Geology-Resources

PGM deposits are associated with magmatic intrusions of mafic and ultramafic rocks. They also occur to a lesser extent as placer deposits. Layered deposits associated with stratiform complexes are the only ones mined principally for the PGM, with nickel, copper, and cobalt sometimes produced as byproducts. These are found in the Bushveld Complex, Republic of South Africa, and the Stillwater Complex, United States.

In other PGM deposits, such as those found in the Sudbury Complex, Canada, and Noril'sk, U.S.S.R., the PGM are produced as byproducts of nickel and copper mining.¹

In the Republic of South Africa, it is interesting to note that base metals such as nickel and copper are important in generating revenues from the Merensky and Platreef ores. This is not the case at

the Stillwater Mine in the United States, where platinum and palladium contribute almost 100% of revenues.

Technology

Processing.—The processing of PGM ore entails four general steps: mining, concentrating, smelting, and refining. In the concentrating step, platinum ore is crushed and treated by froth flotation. The concentrates are dried, sometimes roasted, and then fused in a smelter furnace, producing a sulfide matte containing the PGM. The matte is treated in a refinery using solvent-extraction techniques to separate and purify the six PGM.

Recycling.—In North America, PGM are recovered by a small number of scrap refiners, as shown in table 1. Other companies collect scrap materials such as catalysts and PGM-bearing solutions and process them to increase the grade. These upgraded secondary materials are then sold to refiners. For example, Multi-Metco Inc., Anniston, AL, produces about a 90% concentrate of PGM from scrapped autocatalysts, which in turn is refined by another company. World Resources Co., McLean, VA, collects electroplating solutions, upgrades them, and sells the concentrate to another refiner. Most companies specialize in refining or upgrading a particular type of scrap, such as petroleum catalysts, autocatalysts, or electronic scrap.

Refiners often charge a fee or toll to "toll refine" scrap, ownership of the

PGM content of the scrap remaining with the customer. For example, a refiner and/or fabricator would replace worn out catalyst with fresh catalyst and charge the customer for the refining and fabrication costs. In other cases, refiners purchase scrap, process it, and sell the refined metal. When scrap changes ownership in this way, it is referred to as nontoll scrap.

For statistical purposes, nontoll refined scrap is considered as old scrap and is added to supply, along with newly mined metal.

Because of their high value, PGM are routinely recovered from petroleum catalysts, chemical catalysts, automobile catalysts, glass fiber bushings, electronic scrap, laboratory equipment, dental materials, and jewelry.

Major collectors and refiners of autocatalysts are shown in table 2. In the United States, only Multi-Metco refined any substantial quantities of autocatalyst PGM. Multi-Metco's output required further processing by other companies to produce commercial-grade metal. The other major refiners of scrapped automobile catalysts are in Belgium, Canada, and Japan.

Japanese companies that recycled precious metals from spent catalysts were: Asaka Riken Kogyo, Ishifuku Kinzoku Kyokai, N.E. Kemkat, Nippon Kogyo, Hakko Kagaku Kogyo, Matsuda Precious Metals, Sankin Recycling, Yokohama Metals, and Chugai Kogyo.²

Because used precious-metal scrap varies widely in value and grade, proper sampling and assaying is important to the industry. Fire assay techniques have long been used to determine the presence of precious metals. In addition to fire assays, PGM can be determined by chemical methods and instrumental methods such as X-ray fluorescence and spectrochemical methods.³

A list of independent PGM assayers is shown in table 3. The list is meant to be a sample rather than a complete list of assayers.

The U.S. Bureau of Mines released a new publication that traces the flow of PGM through their metallurgical, catalytic, and chemical applications and

highlights areas in which significant losses occur because of downgrading, export, or disposal.⁴

Economic Factors

Futures contracts are traded on the New York Mercantile Exchange (NYMEX) and the Tokyo Commodity Exchange for Industry (TOCOM), and to a lesser extent on the MidAmerica Exchange.⁵ Futures contracts help producers and consumers of platinum and palladium lock in prices and allow speculators an opportunity to make profits. By comparing the current price with the price for future delivery, one can surmise whether market participants expect prices to rise or fall.

Platinum and palladium futures contracts, specifying 99.95% metal content, were traded on the NYMEX in units of 50 and 100 troy ounces, respectively. Table 4 shows the number of contracts traded on the last trading day of the year for 1988 through 1991.

Trading of platinum futures contracts on the TOCOM began in 1984. The contract unit is 500 grams, the quality specifications are 99.9% purity, and prices are quoted in Japanese yen per gram.

In London, prices of physical platinum and palladium bullion are set each day in the morning and afternoon for the wholesale market. The eight companies participating in establishing prices are members of the London-Zurich Good Delivery Agreement, which sets standards for platinum and palladium trading in Europe. London and Zurich are the two most important European trading centers for platinum and palladium.

A time series of historical prices for each of the six PGM and a brief discussion of factors influencing prices are given in a U.S. Bureau of Mines publication entitled, "Nonferrous Metal Prices in the United States Through 1988."⁶

ANNUAL REVIEW

Legislation and Government Programs

The California Air Resources Board, Mobile Source Div., issued a summary of its mobile source emissions standards. All 1995 and later passenger cars and light-duty trucks, weighing up to 3,750 pounds, are required to emit no more than 0.25 gram per mile (gpm) nonmethane hydrocarbons (NMHC), 3.4 gpm carbon monoxide (CO), and 0.4 gpm oxides of nitrogen (NO_x) for the first 50,000 miles. From 50,000 miles up to 100,000 miles, the requirement becomes 0.31 gpm NMHC, 4.2 gpm CO, and no requirement for NO_x. The requirement for diesel cars and light-duty trucks weighing up to 3,750 pounds, up to 100,000 miles, is 0.31 gpm NMHC, 4.2 gpm CO, and 1.0 gpm NO_x.⁷

Strategic Considerations

Although some platinum and palladium was produced at the only PGM mine in the United States, the Stillwater Mine, the great majority of PGM consumed in the United States was imported.

There were no changes in inventories of platinum, palladium, and iridium in the National Defense Stockpile in 1991. No purchases of rhodium or ruthenium were made, even though there is a stockpile goal for these two metals.

Production

The Stillwater Mine, southwest of Billings, MT, was operated by the Stillwater Mining Co. (SMC), owned 50% by Chevron Corp. and 50% by Manville Corp. Estimates from published sources showed that production of PGM at the mine increased slightly in 1991. As a result of weak prices for platinum and palladium, a plan that was to have doubled ore production to 2,000 short tons per day was postponed. Small amounts of PGM were recovered by other companies as byproducts of domestic copper refining.

Consumption and Uses

Reported sales of PGM by refiners is shown in table 7. For comparison purposes, the calculated apparent consumption for the individual PGM is also shown. Reported consumption for all PGM, with the exception of osmium, declined in 1991.

A summary of the typical uses for each PGM is shown in tables 8 and 9. Platinum, palladium, and rhodium were used in emission catalysts for light trucks (trucks weighing 14,000 pounds or less, gross weight) and automobiles. An informal survey of automobile catalyst manufacturers indicated that a typical emission catalyst in 1991 contained a total of about 2.7 grams PGM (approximately 2.18 grams platinum, 0.31 gram palladium, and 0.31 gram rhodium).

There were variations in the quantities of PGM in each catalyst, depending on the vehicle's engine size, the normal operating temperature of the engine, and the manufacturer of the catalyst.

In electronic applications, ruthenium was the principal PGM used in thick film resistors, and palladium was the principal PGM used in thick film conductors, multilayer ceramic capacitors, and connectors. Platinum "targets" were used for sputtering thin films on circuit boards. Platinum-rhodium alloys were used for manufacturing thermocouples for precise temperature measurement.

For glass applications, most of the PGM, specifically platinum, rhodium, and palladium, were used in bushings for the extrusion of textile (continuous filament) glass fiber.

The nonautomotive catalyst applications of PGM were numerous. The petroleum refining industry used PGM, principally platinum, in reforming, cracking, and isomerization reactions. Chemical catalysts containing platinum and rhodium were used in inorganic syntheses of nitric acid and hydrogen cyanide. Palladium was used in the production of hydrogen peroxide. A wide variety of organic chemicals and pharmaceuticals were produced using PGM catalysts.

Stocks

In addition to the reported stocks held by refiners, importers, and dealers, end users held sizable quantities of PGM that were not reported to the U.S. Bureau of Mines.

Markets and Prices

The average dealer price for platinum was \$371 per troy ounce in 1991, its lowest level in 6 years; while the average dealer price for palladium was \$87 per ounce, its lowest level in 9 years. A recession in the U.S. automobile industry and record-high exports of platinum by the U.S.S.R. contributed to a surplus of supply relative to demand for platinum and palladium.

In May, Nissan Motors announced that it had developed a palladium-only catalytic converter. News of the announcement caused an immediate reaction in markets in New York, causing platinum prices to drop and palladium prices to rise temporarily. In June, Isuzu Motors announced that it had developed a palladium catalytic converter for use on its 1994 model 3-ton trucks for the U.S. market. The Isuzu announcement further depressed platinum prices.

Foreign Trade

Imports of rhodium were down sharply from the record-high level of 13 metric tons imported in 1990, as shown in table 13. In 1991, imports from the Republic of South Africa represented 62% of total U.S. rhodium imports, 73% of total platinum imports, and 31% of total palladium imports.

World Review

Capacity.—Capacity for PGM production is generally cited in terms of platinum capacity. The data in table 14 represent rated capacity, defined as the maximum quantity that can be produced on a normally sustainable long-term operating rate, based on the physical equipment of the plant and routine operating procedures for labor, energy,

materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

Japan.—Japan PGM, a joint venture owned by Dowa Mining and Tanaka Kikinzoku Kogyo, planned to build a plant to recover PGM from spent autocatalysts in Kosaka, Akita, Japan. The plant was scheduled to start up in April 1992 with an annual capacity of 5,000 metric tons of catalysts to recover 4.5 metric tons of platinum, 1.8 metric tons of palladium, and 0.5 metric ton of rhodium.

Demand for platinum in Japan was about 64 metric tons, up from 58 metric tons in 1990. Of this amount, about 39 metric tons was used in jewelry.

South Africa, Republic of.—Barplats canceled development of its underground Crocodile River (formerly Lefkochrysos) platinum mine because of prevailing low PGM prices and high operating costs. The mine would have produced annually about 2,800 kilograms of platinum and 370 kilograms of rhodium. Only a month earlier, in August, Impala Platinum Holding Ltd. acquired a 38% stake in Barplats.

Labor problems and refining bottlenecks at Impala caused the company to lose production and required it to buy metal to maintain supplies to its customers.

Rustenburg Platinum Mines Ltd. confirmed plans to develop the Potgietersrust Mine on the Platreef by mid-1993. The mine was expected to produce about 1,600 kilograms of platinum per year.

U.S.S.R.—Soviet sales of platinum to the West reached a record high of 34 metric tons in 1991, with a large amount initially going to Switzerland. Johnson Matthey PLC reported that some of the platinum was lent or swapped, but most had been sold by the year's end to raise foreign exchange. In addition to

platinum, the U.S.S.R. reportedly shipped a large quantity (1,550 kilograms) of rhodium to Switzerland in May 1991 to be used as collateral against foreign exchange loans. Johnson Matthey, in its Platinum 1992 report, speculated that this large quantity of rhodium was never sold but rather returned to the U.S.S.R.

During 1991, sales of PGM were shared by Almazjuvelirexport (Almaz) and the Soviet Bank for Foreign Economic Affairs, Vneshekonombank. By the end of the year, the Government declared that Almaz would resume its monopoly role for selling PGM.

Current Research

The Bureau's Reno Research Center investigated the use of bacteria to oxidize flotation concentrate from the Stillwater Mine. After bacterial pretreatment, tests were conducted to determine if the PGM could be extracted from the biooxidized residue using cyanide. In the most successful test, 34% of the platinum, 75% of the palladium, 94% of the rhodium, and 97% of the gold was removed from the biooxidized concentrate.⁸

In another study, the Reno Research Center investigated leaching automobile catalysts with sodium cyanide (NaCN) solutions at high temperatures to recover PGM. The feed was virgin monolith rejects, used monoliths, and used pellet catalysts. Leaching with a 5% NaCN solution for 1 hour at 160° C dissolved more than 97% of the PGM in the virgin monolith, 85% of the PGM in the used monolith, and 90% of the PGM in the used pellet catalyst. More than 99.8% of the dissolved PGM was recovered as a precipitate by heating the solution to 250° C for 1 hour in an autoclave. The cyanide complexes were decomposed, and free cyanide was destroyed.⁹

Corning Inc. said it had developed a new substrate for catalytic converters that incorporates an electrically heated metal monolith used in conjunction with a conventional ceramic monolith, all contained within the same catalytic converter unit. The metal monolith is

designed to heat up exhaust gases almost instantly after an automobile has been started and thus promote catalytic activity. After the first 2 minutes of engine operation, the ceramic monolith begins to operate, replacing the function of the metal monolith. Using both monoliths will help automobile companies meet future strict emission regulations.

In July, ARCO Incorporated announced that it had developed a low-sulfur, reformulated gasoline designed to reduce automobile emissions. While not designed to eliminate the use of PGM in autocatalysts, reformulated gasoline may enhance the appeal of palladium-base autocatalysts that are easily "poisoned" by contaminants. The reformulated gasoline, called EC-X, reportedly reduces emissions of hydrocarbons, nitrous oxides, and carbon monoxide by about 25%; however, the gasoline costs about 16 cents per gallon more than conventional gasoline. Because of its high cost, ARCO will not produce EC-X unless it becomes mandatory in order to meet clean air requirements in California, which has traditionally had the toughest standards in the Nation. The Western States Petroleum Association, representing most of California's major refiners, estimated that reformulated gasoline, if needed to meet present air quality standards for California, will require between \$6 billion and \$10 billion in capital investment. There is considerable debate within California about how strict the air standards should be. The question of whether other States will adopt California's standards or possibly adopt stricter standards than California remains unanswered.

OUTLOOK

It is difficult to predict future supplies for PGM from the former U.S.S.R., given that region's tenuous economic circumstances. However, assuming that enough economic aid from Western countries is forthcoming, PGM production will probably continue to rise or at least be maintained. The Republic of Russia has nearly all of the former

U.S.S.R.'s PGM reserves within its borders.

Future demand for PGM should continue to grow worldwide given the strong demand for a cleaner environment. Catalytic converters for controlling automobile emissions are currently used in Australia, Canada, Japan, Mexico, the Republic of Korea, Taiwan, the United States, and many Western European nations. Brazil, Hong Kong, Indonesia, Malaysia, Singapore, and Thailand are expected to start using catalytic converters in the very near future. The potential market for the catalytic converter is huge given the fact that there are 500 million motor vehicles worldwide.

In the United States, California has for years had the most stringent automobile emission regulations, setting the tone for Federal standards. The California Air Resources Board is seeking to introduce zero emissions for 2% of vehicles by the year 2000. Some other States, such as New York and Massachusetts, are opting for California standards instead of the more lenient Federal standards.

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TABLE 1
SELECTED NORTH AMERICAN PLATINUM-GROUP METAL
REFINERS AND FABRICATORS

Company	Type	Plant location	Specialty
AT&T/Nassau Metals	Refiner	Gaston, SC	Electronics.
Do.	do.	Staten Island, NY	Do.
Degussa/Metz	Refiner, fabricator	South Plainfield, NJ	All
Do.	Fabricator	Burlington, Ontario	Autocatalysts.
Du Pont Corp.	do.	Wilmington, DE	Electronics.
Engelhard Corp.	Refiner, fabricator	Carteret, NJ	All.
Do.	Fabricator	Seneca, SC	Catalysts.
Gemini Industries	Refiner	Santa Ana, CA	Do.
Handy & Harman	Refiner, fabricator	South Windsor, CT	Electronics.
Do.	do.	South Plainfield, NJ	Do.
Johnson Matthey Inc.	do.	West Deptford, NJ	All.
Martin Metals Inc.	Refiner	Los Angeles, CA	Electronics.
Multi-Metco Inc.	do.	Anniston, AL	Autocatalysts.
Noranda Ltd.	do.	Montreal, Quebec	Electronics.
PGP Industries Inc.	Refiner, fabricator	Santa Fe Springs, CA	Do.

TABLE 2
COLLECTORS AND REFINERS OF AUTOCATALYSTS

Company	Type	Plant location
A-1 Specialized Services & Supplies Inc.	Collector	South River, NJ.
Bowden Industries Inc.	do.	Covington, TN.
Brown Recycling & Manufacturing	do.	Somerville, AL.
Catalytic Converter Refining Co.	do.	Northlake, IL.
INCO Ltd.	Refiner	Sudbury, Canada.
Metallurgie Hoboken Overpelt/SGM	do.	Hoboken, Belgium.
Multi-Metco Inc.	do.	Anniston, AL.
Nissan Group/Ikeda	do.	Japan.
Parkans International Inc.	Collector	Houston, TX.
Sumitomo Metal Mining Co.	Refiner	Japan.
U.S. Scrap Co.	Collector	Los Angeles, CA.

TABLE 3
INDEPENDENT PLATINUM-GROUP METAL ASSAYERS

Company	Location
Accredited Laboratories Inc.	Carteret, NJ.
Alex Stewart (Assayers) Ltd.	Merryside, England.
Alfred H. Knight Laboratories Ltd.	Pompton Lakes, NJ.
Bondar-Clegg	Ottawa, Canada.
International Testing Laboratories	Newark, NJ.
Ledoux & Co.	Teaneck, NJ.
Umpire & Control Services, Inc.	West Babylon, NY.

TABLE 4
NYMEX TRADING VOLUME FOR FUTURES CONTRACTS,
DECEMBER 31

(Number of contracts)

	1988	1989	1990	1991
Platinum ¹	1,460,455	1,190,529	820,934	940,330
Palladium ²	139,883	200,892	95,642	243,226

¹50 troy ounces per contract.

²100 troy ounces per contract.

TABLE 5
SALIENT PLATINUM-GROUP METALS¹ STATISTICS

(Kilograms)

	1987	1988	1989	1990	1991
United States:					
Mine production:²					
Platinum	780	1,240	1,430	1,810	1,730
Palladium	2,330	3,730	4,850	5,930	6,050
Value ³ thousand dollars	\$23,606	\$35,601	\$45,764	\$48,911	\$37,558
Refinery production:					
Primary refined	191	297	339	64	80
Secondary:					
Nontoll-refined	5,118	4,788	3,933	5,819	4,907
Toll-refined	44,935	46,403	46,253	65,429	69,936
Total refined metal	50,243	51,488	50,525	71,312	74,923
Stocks, yearend:					
Industry (refined)	38,412	35,514	32,543	30,324	24,313
National Defense Stockpile:					
Platinum	14,079	14,079	14,079	14,079	14,079
Palladium	39,334	39,334	39,334	39,334	39,334
Iridium	920	920	920	920	920
Exports:					
Refined ⁴	13,423	20,301	23,082	20,148	27,401
Total	22,031	28,787	38,301	55,044	39,624
Imports for consumption:					
Refined ⁴	98,878	110,947	111,107	120,631	121,741
Total	118,397	124,324	113,278	125,354	125,661
Imports, general	118,397	124,324	113,278	125,354	125,661
Consumption (reported sales to industry)	60,280	70,998	78,483	77,487	62,751
Consumption, apparent ⁵	95,458	103,302	101,209	117,043	113,350
Net import reliance ⁶ as a percent of apparent consumption	91	91	90	88	89
Price, dealer, average, per ounce:					
Platinum	\$553	\$523	\$507	\$467	\$371
Palladium	\$130	\$123	\$144	\$114	\$87
Rhodium	\$1,222	\$1,218	\$1,300	\$3,565	\$3,739
World: Mine production	270,281	280,160	279,726	288,502	291,678

¹Estimated. ²Revised.

³The platinum-group comprises six metals: platinum, palladium, iridium, osmium, rhodium, and ruthenium.

⁴Estimates for the Stillwater Mine are from published sources. A very small quantity of byproduct platinum and palladium produced from gold-copper ores was excluded.

⁵Value based on dealer prices.

⁶Excludes ores and scrap.

⁷Includes mine production plus nontoll-refined production plus refined imports for consumption minus refined exports plus or minus changes in Government and industry stocks.

⁸Refined imports for consumption minus refined exports plus or minus changes in Government and industry stocks.

TABLE 6
PLATINUM-GROUP METALS REFINED IN THE UNITED STATES

(Kilograms)

	Platinum	Palladium	Iridium	Osmium	Rhodium	Ruthenium	Total ¹
PRIMARY METAL²							
Nontoll-refined:							
1987	32	158	—	—	—	—	191
1988	46	248	2	—	(³)	—	297
1989	47	289	2	—	—	2	339
1990	2	62	—	—	—	—	64
1991	7	73	—	—	—	—	80
SECONDARY METAL							
Nontoll-refined:							
1987	1,180	3,743	4	19	123	49	5,118
1988	1,133	3,545	4	—	104	2	4,788
1989	1,134	2,664	6	—	94	35	3,933
1990	¹ 1,928	³ 3,672	7	—	¹ 178	34	⁵ 5,819
1991	2,221	2,378	80	—	215	13	4,907
Toll-refined:							
1987	22,580	19,169	102	25	1,895	1,164	44,935
1988	22,884	20,923	252	19	1,826	499	46,403
1989	24,058	20,037	219	1	1,565	373	46,253
1990	³ 38,475	² 32,297	¹ 130	—	³ 3,094	⁴ 433	⁶ 65,429
1991	39,517	26,245	128	24	3,080	943	69,936
1990 TOTALS¹							
Total primary	2	62	—	—	—	—	64
Total secondary	⁴ 40,403	² 26,969	¹ 136	—	³ 3,272	⁴ 468	⁷ 71,248
Total refined metal	<u>⁴40,405</u>	<u>²27,030</u>	<u>¹136</u>	<u>—</u>	<u>³3,272</u>	<u>⁴468</u>	<u>⁷71,312</u>
1991 TOTALS¹							
Total primary	7	73	—	—	—	—	80
Total secondary	41,738	28,622	209	24	3,295	955	74,843
Total refined metal	<u>41,744</u>	<u>28,695</u>	<u>209</u>	<u>24</u>	<u>3,295</u>	<u>955</u>	<u>74,923</u>

¹Revised.

²Data may not add to totals shown because of independent rounding.

³"Toll-refined" data were not reported for years 1987-91.

⁴Less than 1/2 unit.

TABLE 7
**PLATINUM-GROUP METALS¹ SOLD TO CONSUMING INDUSTRIES
 IN THE UNITED STATES**

(Kilograms)

Year and industry	Platinum	Palladium	Iridium	Osmium	Rhodium	Ruthenium	Total ²
1987:							
Reported	25,471	30,956	250	29	2,692	882	60,280
Apparent consumption ³	34,703	49,967	569	184	7,205	2,830	95,458
1988:							
Reported	31,125	34,241	495	23	3,292	1,821	70,998
Apparent consumption ³	39,208	52,342	721	76	7,294	3,661	103,302
1989:							
Reported	33,698	39,273	400	57	3,019	2,037	78,483
Apparent consumption ³	47,035	45,299	604	30	6,112	2,129	101,209
1990:							
Automotive ⁴	20,967	2,995	—	—	2,995	—	26,957
Chemical	2,080	2,369	22	—	169	16	4,654
Dental and medical	687	6,133	104	40	2	7	6,974
Electrical	3,907	17,997	111	—	274	1,406	23,698
Glass	431	346	1	—	31	1	810
Jewelry and decorative	431	177	11	—	195	8	818
Petroleum	3,274	1,488	—	—	—	—	4,762
Miscellaneous	4,280	3,612	199	1	520	202	8,814
Total ²	36,055	35,116	448	40	4,187	1,641	77,487
Apparent consumption ³	49,875	51,464	649	56	12,311	2,685	117,043
1991:							
Automotive ⁴	18,643	2,669	—	—	2,669	—	23,981
Chemical	881	1,552	32	—	183	40	2,688
Dental and medical	603	4,819	118	79	1	14	5,634
Electrical	3,923	12,875	129	—	67	1,436	18,430
Glass	127	—	—	—	6	4	138
Jewelry and decorative	639	374	6	—	193	3	1,214
Petroleum	3,163	171	—	—	—	10	3,344
Miscellaneous	3,157	3,405	37	—	660	64	7,322
Total ²	31,136	25,865	321	79	3,778	1,571	62,751
Apparent consumption ³	45,631	57,503	600	55	6,964	2,597	113,350

¹Revised.

²Comprises primary and nonrefined secondary metals.

³Data may not add to totals shown because of independent rounding.

⁴Defined as mine production plus nonrefined production of secondary metal plus refined imports minus refined exports plus beginning stocks minus ending stocks. In 1987 and 1988, unspecified PGM imports and exports were divided evenly between platinum and palladium. Export data for iridium, osmium, and ruthenium are not available separately; in this calculation, the collective export figure was assigned to ruthenium.

⁵1987-91 platinum, palladium, and rhodium sales to the automotive industry are estimated based on U.S. light truck sales and U.S. automobile production.

**TABLE 8
TYPICAL USES OF PLATINUM, PALLADIUM, AND RHODIUM**

Platinum	Palladium	Rhodium
Automobile catalyst	Automobile catalyst	Acetic acid catalyst.
Cancer drugs	Dental alloys	Automobile catalyst.
Coins	Hydrocracking catalyst	Glass bushings.
Cracking catalyst	Hydrogen peroxide catalyst	Nitric acid catalyst.
Crucibles	Multilayered capacitors	Thermocouples.
Fuel cell electrode	Thick films pastes	
Glass bushings	Vinyl acetate catalyst	
Hydrogen cyanide catalyst		
Isomerization catalyst		
Jewelry		
Nitric acid catalyst		
Reforming catalyst		
Targets for thin films		
Thermocouples		

**TABLE 9
TYPICAL USES OF RUTHENIUM, IRIDIUM, AND OSMIUM**

Ruthenium	Iridium	Osmium
Caustic soda electrode	Caustic soda electrode	Biological staining.
Chlorine electrode	Chlorine electrode	Pharmaceutical catalyst.
Resistor circuits	High-temperature crucibles	
	Reforming catalyst	

**TABLE 10
REFINER, IMPORTER, AND DEALER STOCKS OF REFINED
PLATINUM-GROUP METALS¹ IN THE UNITED STATES, DECEMBER 31**

(Kilograms)

Year	Platinum	Palladium	Iridium	Osmium	Rhodium	Ruthenium	Total
1987	19,004	17,356	506	1	996	549	38,412
1988	18,438	14,837	432	8	1,165	634	35,514
1989	14,791	15,182	522	36	1,096	916	32,543
1990	13,421	14,425	483	55	1,089	851	30,324
1991	10,349	12,263	483	46	318	854	24,313

¹Includes metal in depositories of the New York Mercantile Exchange (NYMEX); on Dec. 31, 1991, this comprised 2,916 kilograms of platinum and 3,505 kilograms of palladium.

TABLE 11
AVERAGE PRODUCER AND DEALER PRICES¹ OF PLATINUM-GROUP METALS

(Dollars per troy ounce)

	Platinum		Palladium		Rhodium		Iridium		Ruthenium	Osmium
	Producer	Dealer	Producer	Dealer	Producer	Dealer	Producer	Dealer	Dealer	Dealer
1987	600	553	150	130	1,239	1,222	532	363	70	633
1988	600	523	150	123	1,275	1,218	420	306	61	592
1989	600	507	150	144	1,275	1,300	NA	303	62	549
1990:										
January	600	492	150	134	1,275	2,031	(²)	315	63	505
February	600	516	150	135	1,275	2,098	(²)	310	61	444
March	600	494	150	130	1,275	2,058	(²)	310	61	425
April	600	475	150	127	1,275	2,108	(²)	310	61	421
May	600	484	150	118	1,275	2,308	(²)	305	61	400
June	600	479	150	115	1,275	2,960	(²)	305	61	400
July	600	475	150	116	1,275	5,040	(²)	305	61	400
August	600	486	150	115	1,275	5,014	(²)	305	61	400
September	600	458	150	103	1,275	5,271	(²)	305	61	400
October	600	415	150	94	1,275	4,720	(²)	305	59	400
November	600	416	150	93	1,275	4,405	(²)	304	60	400
December	600	414	150	87	1,275	4,769	(²)	309	61	400
Average ³	600	467	150	114	1,275	3,565	NA	307	61	416
1991:										
January	600	400	150	84	1,275	5,348	(²)	300	59	400
February	600	379	150	83	1,275	5,329	(²)	293	58	400
March	600	393	150	84	1,275	5,223	(²)	288	58	400
April	600	394	150	94	1,275	5,086	(²)	285	56	400
May	600	384	150	94	1,275	4,099	(²)	285	59	400
June	600	372	150	96	1,275	3,688	(²)	285	54	400
July	600	372	150	95	1,275	3,693	(²)	284	55	400
August	600	373	150	81	1,275	2,827	(²)	280	55	400
September	600	347	150	81	1,275	2,959	(²)	280	55	400
October	600	359	150	84	1,275	2,713	(²)	270	53	400
November	600	359	150	85	1,275	2,300	(²)	270	50	400
December	600	350	150	80	1,275	1,682	(²)	270	48	400
Average ³	600	371	150	87	1,275	3,739	NA	283	55	400

²Revised. NA Not available.

¹Average prices calculated at the low end of the range and rounded to the nearest dollar.

²Producer prices discontinued Mar. 22, 1989.

³Average yearly prices for platinum, palladium, and rhodium are as published by Metals Week; average yearly prices for iridium, ruthenium, and osmium are calculated by averaging the monthly average prices.

TABLE 12
U.S. EXPORTS OF PLATINUM-GROUP METALS, BY YEAR AND COUNTRY

(Kilograms)

Year and country	Platinum	Palladium	Rhodium	Iridium, osmium, ruthenium	Ores and concentrates	Waste and scrap	Total ¹	
							Quantity	Value (thousands)
1990	7,510	10,887	969	782	409	34,487	55,044	\$415,605
1991:								
Australia	29	28	—	—	—	—	57	590
Austria	—	16	—	—	—	—	16	48
Belgium	1,939	4,493	3	—	840	3,793	11,068	89,725
Brazil	2	17	2	—	—	—	21	148
Canada	932	1,039	34	45	3	486	2,539	35,631
China	23	52	—	22	—	24	121	1,090
France	287	177	—	5	—	28	497	4,467
Germany	814	925	1	18	—	1,328	3,086	33,297
Hong Kong	49	7	5	1	—	23	85	2,003
Italy	344	375	—	—	—	1,662	2,381	22,479
Japan	4,912	2,167	373	39	9	853	8,353	138,555
Korea, Republic of	618	238	105	6	2	—	970	23,202
Netherlands	328	1,151	—	—	—	—	1,480	8,038
Singapore	2	117	—	—	—	—	119	866
Sweden	5	42	—	—	—	238	285	1,048
Switzerland	991	489	—	—	—	176	1,656	22,410
Taiwan	118	1,248	—	3	—	—	1,370	8,251
United Kingdom	1,089	676	20	151	2	2,748	4,686	56,270
Other	373	380	49	20	5	1	829	13,466
Total ¹	12,860	13,638	592	312	863	11,360	39,624	461,588

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 13
U.S. IMPORTS FOR CONSUMPTION OF PLATINUM-GROUP METALS, BY YEAR AND COUNTRY

(Kilograms)

Year and country	Platinum	Palladium	Rhodium	Ruthenium	Iridium	Osmium	Waste and scrap	Ores	Total	
									Quantity	Value (thousands)
1990	52,277	51,992	13,098	2,586	603	75	4,614	109	125,354	\$1,905,830
1991:										
Belgium	1,976	8,503	188	—	—	—	101	—	10,768	74,842
Canada	6	1,960	1	—	—	—	775	—	2,742	20,085
France	7	235	38	—	—	—	34	—	314	7,812
Germany, Federal Republic of	3,566	511	471	29	84	—	116	—	4,778	114,789
Hong Kong	—	—	1	—	—	—	195	—	196	2,501
Italy	101	—	19	—	—	—	1	—	121	3,820
Japan	332	2,709	2	—	—	—	96	—	3,140	14,296
Mexico	—	2	—	—	—	—	144	—	146	1,526
Netherlands	—	1	30	—	—	—	176	—	207	9,631
Norway	649	860	27	—	—	—	8	—	1,543	9,719
South Africa, Republic of	37,475	18,776	4,072	2,305	363	46	44	—	63,082	1,041,796
Switzerland	690	113	3	—	4	—	260	—	1,069	13,561
Taiwan	—	—	—	—	—	—	146	—	146	2,533
U.S.S.R.	291	16,470	832	—	7	—	—	—	17,600	158,680
United Kingdom	5,006	10,197	847	252	56	—	1,036	—	17,394	241,290
Other	1,369	213	38	—	4	—	758	31	2,413	25,983
Total ¹	² 51,468	60,551	6,570	2,587	520	46	3,889	31	² 125,661	1,742,866

¹Data may not add to totals shown because of independent rounding.
²Of this amount, 1,237 kilograms was in the form of platinum coins.

Sources: Bureau of the Census and U.S. Bureau of Mines.

TABLE 14
PLATINUM ANNUAL MINE
CAPACITY OF MAJOR
PRODUCING COMPANIES, AS OF
DECEMBER 31, 1991

(Kilograms)

	Capacity
North America:	
INCO Ltd.	3,800
Falconbridge Ltd.	1,300
Stillwater Mining Co. ¹	1,800
Total	6,900
Africa:	
Rustenburg Platinum Mines Ltd. ²	46,000
Impala Platinum Holdings (Pty.) Ltd. ³	35,000
Western Platinum Ltd. (Lonrho) ⁴	9,000
Total	90,000
World total (rounded)	97,000

¹Jointly owned by Chevron Corp. and Manville Corp.

²Owms Lebowa Platinum Ltd.; plans to develop Potgietersrust Mine.

³Owms Barplats.

⁴Owms the Karoo Mine.

TABLE 15
PLATINUM-GROUP METALS: WORLD PRODUCTION, BY COUNTRY¹

(Kilograms)

Country ²	1987	1988	1989	1990	1991 ³
Australia, metal content, from domestic nickel ore:³					
Platinum	130	106	100	100	100
Palladium	490	411	400	400	400
Canada:⁴					
Platinum	4,354	5,393	4,244	4,829	4,384
Palladium	5,910	5,643	4,442	5,044	6,028
Other	666	1,505	1,184	1,336	548
Colombia: Placer platinum	638	815	973	1,316	1,550
Ethiopia: Placer platinum⁶	1	1	2	2	2
Finland:					
Platinum	120	54	60	60	60
Palladium	89	106	100	100	100
Japan, metal recovered from nickel-copper ores:⁷					
Platinum	753	647	1,031	1,425	988
Palladium	1,417	1,170	821	1,047	1,053
South Africa, Republic of: Platinum-group metals from platinum ore:⁸					
Platinum	78,400	80,200	81,500	85,800	90,000
Palladium	33,900	34,400	35,800	38,300	41,000
Other	15,700	17,000	15,000	15,800	16,000
U.S.S.R.: Placer platinum and platinum-group metals recovered from nickel-copper ores:⁹					
Platinum	31,000	32,000	32,000	31,000	30,000
Palladium	83,000	85,000	85,000	84,000	82,000
Other	10,400	10,500	10,500	10,000	9,500
United States: Platinum-group metals from palladium ores:⁹					
Platinum	780	1,240	1,430	1,810	1,730
Palladium	2,330	3,730	4,850	5,930	6,050
Yugoslavia:					
Platinum	24	23	23	21	15
Palladium	132	142	199	130	120
Zimbabwe:					
Platinum	18	28	25	21	20
Palladium	29	46	43	31	30
Total	270,281	280,160	279,726	288,502	291,678
Of which:					
Platinum	116,218	120,507	121,387	126,383	128,849

See footnotes at end of table.

TABLE 15—Continued
 PLATINUM-GROUP METALS: WORLD PRODUCTION, BY COUNTRY¹

(Kilograms)

Country ²	1987	1988	1989	1990	1991 ³
Total—Continued:					
Of which—Continued:					
Palladium	⁴ 127,297	⁴ 130,648	⁴ 131,655	⁴ 134,982	136,781
Other	⁴ 26,766	⁴ 29,005	⁴ 26,684	⁴ 27,136	26,048

¹Estimated. ²Revised.

¹Table includes data available through Apr. 29, 1992. Platinum-group metal production by Germany (western states), Norway, and the United Kingdom is not included in this table because the production is derived wholly from imported metallurgical products and to include it would result in double counting.

²In addition to the countries listed, China, Indonesia, Papua New Guinea, and the Philippines are believed to produce platinum-group metals, and several other countries may also do so, but output is not reported quantitatively, and there is no reliable basis for the formulation of estimates of output levels. However, a part of this output not specifically reported by country is presumably included in this table credited to Japan. (See footnote 7).

³Partial figure; excludes platinum-group metals recovered in other countries from nickel ore of Australian origin; however, a part of this output may be credited to Japan. (See footnote 7).

⁴Unless otherwise indicated, Canadian data show estimated proportions of platinum, palladium, and other platinum-group metals within the reported total. Yearly totals have been reported, in kilograms, as follows: 1987—10,930; 1988—12,541; 1989—9,870; 1990—11,209; and 1991—10,960 (estimated).

⁵Reported figure.

⁶Data are for years ending June 30 of that stated.

⁷Japanese figures do not refer to Japanese mine production, but rather represent Japanese smelter-refinery recovery from ores originating in a number of countries; this output cannot be credited to the country of origin because of a lack of data. Countries producing and exporting such ores to Japan include (but are not necessarily limited to) Australia, Canada, Indonesia, Papua New Guinea, and the Philippines. Output from ores of Australian, Indonesian, Papua New Guinean, and Philippine origin are not duplicative, but output from Canadian material might duplicate a part of reported Canadian production.

⁸Includes osmiridium produced in gold mines.

⁹Estimates for the Stillwater Mine, from published sources. A very small quantity of byproduct platinum and palladium produced from gold-copper ores was excluded.

POTASH

By James P. Searls

Mr. Searls, a physical scientist and economist, has been the commodity specialist for potash for 12 years. Domestic survey data were prepared by Carleen Militello, statistical assistant; and international data were prepared by Theodore T. Spittal, international data coordinator.

U.S. potash production in terms of potassium oxide (K_2O) equivalent increased about 2% relative to that of 1990, and apparent consumption increased about 3%. The average price, f.o.b. mine, was essentially unchanged (less than 1% increase). Yearend stocks increased about 13% over the ending stocks of 1990 due to unexpectedly slow sales in November and December.

DOMESTIC DATA COVERAGE

The U.S. Bureau of Mines developed potash domestic data from voluntary semiannual surveys of U.S. operations. Of the 12 survey requests sent to operations, 11 responded, representing 98% of total production shown in table 1.

ANNUAL REVIEW

Issues

A competition for the land use in the known potash geographical area has arisen in 1991. An oil and gas industry expressed wishes to drill near or through several potash reserves in the area. Some recent, successful wells have led the oil industry to believe that there was a strong chance of oil underneath unmined potash reserves. The oil well executives have approached the Bureau of Land Management and the U.S. Department of the Interior requesting permission to drill through the potash reserves for the suspected pools of oil.

Drilling through a potash seam precludes the mining of potash in a radius of 305 meters (1,000 feet), equal to the

depth of the seam, around the drill stem. That would diminish reserves by at least 710,750 cubic meters (25,100,000 cubic feet) of ore. Assuming 2,002 kg/cu meters (125 lbs. per cubic foot), this equates to 1,425,000 metric tons¹ (1,570,000 tons) of ore lost per drill hole. Should the companies be searching for oil and drill in the center of every 40 acres, as is the industry accepted practice, the drill holes are close enough together to preempt all of the potash reserves in each of the 40-acre tracts. Beyond this there is a major concern that the methane gas associated with the oil may leak up around the drill string or from a cracked drill string into the mine over miles of distance, which would convert the mine into a "gassy" mine under Mine Safety and Health Administration rules. In that event, vast and expensive modifications would have to be made to the mining, lighting, and power distribution equipment of the whole mine. The costs of these modifications would severely reduce operational profitability and possibly result in the cessation of mining at the affected operations, even in the section of the mine distant from the oil or gas drilling. (See tables 1, 2, 3, and 4.)

Production

Domestic potash production, in K_2O equivalents, increased about 2% in 1991 over that of 1990. Of the total production for the year, 75% was standard, coarse, or granular muriate of potash, also known as potassium chloride, and 12% was sulfate of potash, also known as potassium sulfate. The remaining production included manure

salts, soluble and chemical grades of muriate of potash, and sulfate of potash-magnesia, also known as potassium magnesium sulfate. The terms "standard," "coarse," and "granular" muriate of potash refer to their particle sizes and comprise the "three muriates," a term that ignores the soluble and chemical grades of muriate of potash. "Standard" and "soluble" grades of muriate of potash and sulfate of potash also have industrial end uses. The "sulfates" category combines the sulfate of potash-magnesia data and the sulfate of potash data. "Manure salts" formerly referred to high-grade "run-of-mine" ore and was put on a few crops; 25% K_2O sylvinitic ore is approximately 40% KCl that can be used on sugar beets. The term now refers to a mixture of white muriate of potash and common table salt for industrial uses.

The New Mexico potash producers accounted for 86% of the total marketable potash salts production. Production of crude salts (ore) in New Mexico was 16.3 million tons with an average K_2O content of 13.2%, a 4% decrease in ore grade compared to that of last year. The producers were AMAX Potash Corp. of AMAX Inc., Eddy Potash Inc. of Trans-Resources Inc., IMC Fertilizers Inc. (IMCF), Mississippi Chemical Corp., New Mexico Potash Corp. of Trans-Resources Inc., and Western Ag-Minerals Co. of Rayrock Resources of Canada. All the New Mexico producers, except Western Ag-Minerals, mined sylvinitic ore (the mixture of sylvite and halite from which most muriate of potash originates) and beneficiated the ore into muriate of potash. Several forms of beneficiation

were used: The flotation of sylvite (potassium chloride) away from halite (sodium chloride) occurred at AMAX Potash, Eddy Potash, and Mississippi Chemical. The IMCF plant used both heavy-media separation and flotation, and New Mexico Potash used selective crystallization in its plant. Western Ag-Minerals and IMCF mined langbeinite ore and beneficiated the ore to sulfate of potash-magnesia. The IMCF personnel mined both sylvinitic and langbeinitic ores and reacted fractions of each potash product to produce sulfate of potash. Some muriate of potash from New Mexico was sold to a domestic potassium nitrate manufacturer who produced about 50,000 tons.

In Utah, Moab Salt Inc. produced muriate of potash for Texas-Gulf Chemical Co. from underground bedded deposits by two-well solution mining and solar evaporation. The sylvinitic salts from the solar ponds were beneficiated by flotation to separate the sylvite from the halite. Great Salt Lake Minerals & Chemicals Corp. (GSLMC) produced sulfate of potash from the brines of the North Arm of the Great Salt Lake by solar evaporation and a proprietary process of beneficiation. GSLMC sometimes purchases muriate of potash from other sources for conversion to sulfate of potash owing to an excess of sulfate ions in the lake brine concentrate. For 1991, GSLMC purchased a small amount of muriate of potash from domestic sources; this amount was subtracted from the muriate of potash production and sales data to prevent double counting in the U.S. apparent consumption calculation. The Reilly-Wendover operation of Reilly Industries Inc. plant produced muriate of potash and manure salts by solar evaporation and flotation from near-surface brines at the west end of the Bonneville Salt Flats.

One plant in Utah manufactured sulfate of potash from muriate of potash and sulfuric acid. They reported production of about 12,500 tons for the year. The amount is not included in table 4 because the company does not mine any ore.

In California, the muriate and sulfate of potash (and other products) operation at

Searles Lake owned by North American Chemical Corp. continued to produce by solar evaporation and selective crystallization from the underground brines of the lake bed.

In Michigan, Kalium Chemical Ltd. continued pilot plant development of a deep ore body and the technology to extract potash from that ore body.

Greensand, also known as glauconite, a natural silicate of potassium, aluminum, iron, and magnesium, was produced by Inversand Co., a subsidiary of Hungerford and Terry Inc., near Clayton, NJ. Production and sales information are withheld to avoid disclosing company proprietary data. Processed greensand was sold as a filter media for the removal of manganese, iron, and hydrogen sulfide from drinking water supply systems. Classified raw greensand was resold by Zook and Ranck Inc. as a soil conditioner and as a slowly released potash, with a K_2O equivalent between 5% and 10%, to the organic farmers of North America. (See tables 5 and 6.)

Consumption and Uses

Apparent domestic consumption of all forms of potash in 1991 increased 3% compared with that of last year when all sources of potash are considered.

Shipments from North American potash producers to that region through the first half of the year were above 1990's shipments. After October, heavy rains, sleet, ice, and snow slowed potash shipments in the Midwest. North American producer total shipments were down at the end of the year by about 5% relative to those of last year. Offshore sources of potash apparently reached consumers who were not bothered by the adverse weather. The West South-Central and West North-Central regions were below last year's shipping levels due to the rains in the South and lower wheat plantings in the North. For the domestic potash producers, about 59% of the sales was in the first half of the year.

According to the Potash & Phosphate Institute, the shipments of agricultural potash from Canadian and United States producers decreased 5% from 1990 to

1991. The shipments of nonagricultural potash increased 6% for a total (agricultural plus nonagricultural) decline of 4%. The major States receiving agricultural potash from Canadian and United States producers, in decreasing order, were Illinois, Ohio, Iowa, Indiana, Minnesota, Missouri, and Wisconsin. These seven States received 55% of the total. Domestic producers accounted for 9% of the shipments to Illinois, 4% of the shipments to Ohio, 8% of the shipments to Iowa, 7% of the shipments to Indiana, 2% of the shipments to Minnesota, 65% of the shipments to Missouri, and 1% of the shipments to Wisconsin. The major receivers of domestically produced potash, in decreasing order, were Missouri, Texas, California, Illinois, Arkansas, Florida, and Kansas. These seven States accounted for 61% of the total. The major consumers of sulfates of potash, in decreasing order, were Florida, California, Georgia, Kentucky, and Texas. These five States accounted for 55% of the total. These figures do not account for the imports from the rest of the world. Those tonnages are counted only at the entering port, and the State in which the potash was consumed is not known.

The major States for shipments of nonagricultural potash from Canadian and United States producers, in decreasing order, were Alabama, Ohio, Delaware, and Mississippi. These four States accounted for 66% of the total.

Stocks

Yearend producers' stocks were about 13% higher than those of 1990. Granular muriate of potash product stocks made up about 37% of the total stocks. Sulfates of potash stocks made up about 32% of the total stocks. Yearend stocks represented about 20% of annual production or about 10 weeks of average production. (See table 7.)

Prices

The average annual price, \$178.32 per ton f.o.b. mine, of U.S. potash sales of all types and grades was about 1% greater, less than the rate of inflation of 3.6%, than that of 1990. The average price was \$177.21 per ton for the first half of the year and \$179.85 per ton for the second half of the year. The average annual price of the three grades of muriate was \$132.24, up less than 2% from last year. Standard grade of muriate averaged \$128.75 per ton; coarse grade, \$136.18; and granular grade, \$133.60. The average annual price for all grades of sulfate of potash averaged \$319.43 per ton, an increase of about 0.6%. (See tables 8, 9, 10, and 11.)

Foreign Trade

Total potash exports of the United States as reported by the Bureau of the Census increased 33%, by ton K₂O. Muriate of potash exports increased 64% while sulfate of potash decreased 17%. The major destinations for U.S. potash exports were Latin America and the Pacific Basin. Latin America received about 64% of all U.S. potash shipments. In this region, receiving about 83% of the shipments, in decreasing order, were Brazil, Mexico, Venezuela, Costa Rica, Dominican Republic, and Chile. Muriate of potash was the important shipment to this region, amounting to 88% of total shipments; sulfate of potash only accounted for 7% of the total. The Pacific Basin received about 27% of all U.S. potash shipments. China and Japan, in declining order, received about 92% of the region's shipments. Sulfate of potash was 40% of the shipments to the Pacific Basin, while muriate of potash was 39%, sulfate of potash-magnesia was 19%, and nitrate of potash was 2%.

Potash imports for consumption into the United States as reported by the Bureau of the Census increased about 9% compared with those of 1990. Muriate of potash imports increased about 8%, while sulfate of potash imports increased about 10%. The Federal Republic of Germany increased its imports into the United

States over those of 1990 by about 2% when compared to the combined imports of the former East and West Germany of last year.

Canada provided 93% of all muriate of potash imports and 92% of all imports by K₂O. Canada exported to the United States about 4.17 million tons equivalent or about 74% of apparent consumption. The Commonwealth of Independent States (CIS) was the second largest seller to the United States at 117,700 tons. Israel fell to third place, importing about 1,000 tons less than the CIS but providing both muriate of potash and nitrate of potash. Israeli muriate of potash imports fell to about 50% of 1990's level. (See tables 12, 13, 14, and 15.)

World Review

World production declined about 8% from that of 1990. This is the third year of potash production declines. World prices, as exemplified by the per ton price of standard muriate of potash, f.o.b. Vancouver, Canada,² rose from approximately \$162 per ton (\$97 per metric ton of product) in January-February to \$172 per ton (\$103 per metric ton of product) in March, and \$183 per ton (\$110 per metric ton of product) in April, remaining at that level for the rest of the year. Granular muriate of potash is no longer tied directly to the price of standard, and ranges above and below the price of standard grade at this port according to its own supply-demand balance.

Argentina.—Potasio Rio Colorado S.A., formed by Grupo TEA companies, is investigating a 150,000-ton-per-year production site near Malargue, Province of Mendoza, by solution mining and solar evaporation. The company has received a loan from the Inter-American Investment Corp. The American firm FMC Corp. has commenced exploration for lithium in the Salar del Hombre Muerto. Should this site be developed there is a slight chance that potash will be coproduced from this site.

Bolivia.—The American firm FMC Corp. is continuing exploration for lithium in the Salar de Uyuni. Should this site be developed there is a slight chance that potash will be coproduced from this site.

Brazil.—Companhia Vale do Rio Doce leased the Taquari-Vassouras potash mine from Petrobras with the intention of profitable production after some additional investment.

Commonwealth of Independent States.—The Uralkali Combine north of Perm was divided into two combines, one retaining the name Uralkali but including only the Berezniki plants. The Solikamsk mines were renamed the Silvinit Combine. The Byeloruskaliy Combine, the Soligorsk mines, came under the control of the Byelorussian Government. The Byeloruskaliy mines produced about 50% of CIS production. The Ukraine Government assumed control over the mines in the Kalush-Stebnik regions. A potash storage building was being built near Vladivostok at the Vostochny seaport with the help of the National Federation of Agricultural Co-operative Associations, known as Zen-noh, of Japan.

The miners at the Soligorsk Mines struck for 9 days starting April 17, during a confrontation with President Gorbachev concerning the then-Republics' powers and control over internal resources.

Soyuzagrokhimexport, the former Soviet agricultural chemical exporting agency, formed a joint-venture company, known as Agrovit, with a U.S. company that was to handle potash and urea in to the Americas.

Germany, Federal Republic of.—Kali und Salz AG closed the Salzdetfurth Mine and its 350,000 tons of annual capacity late in the year and projected closure of the Niedersachsen-Reidel Mine and its 200,000 tons of annual capacity in 1994. This would reduce the Kali und Salz capacity to 2.35 million tons of annual capacity in 1992 and 2.15 million tons in

1995. *Mitteldeutsche Kali AG* of the former East Germany closed down five mines, Bleicherode, Dorndorf, Sollstet, and Volkenrode, by midyear, and Sondershausen by yearend. *Mitteldeutsche Kali* has shut down about 0.9 million tons of annual capacity, bringing it to 2.2 million tons. The remaining mines will be Bischofferode, Merkers, Rossleben, Unterbreizbach, and Zielitz.

Israel.—*Haifa Chemical Ltd.* began a study for an additional 45,000-ton annual capacity potassium nitrate plant. In 1990, a fire in an adjoining phosphoric acid facility stopped production for a week in the present 135,000 tons of annual capacity of potassium nitrate facility. Twenty-five percent of the *Israel Chemicals Ltd.* stock was sold on the Tel Aviv stock market to Israeli owners. Another 15% was to be sold to a "strategic" partner. Thirty-two percent is planned to be sold on the Tel Aviv and other, foreign stock markets. The Government of Israel will continue to own 28% of the company.

Jordan.—During the summer of 1990 the Arab Potash Co. announced plans to expand from 0.84-million-ton-per-year capacity to 1.1 million tons per year by mid-1994. The company envisions an expansion to a 1.3-million-ton-per-year capacity by the year 2000. The Persian Gulf War in Iraq and Kuwait had little effect on the operation of the potash operation except to briefly raise shipping insurance premiums and thereby diminish shipping traffic from Aqaba for several weeks.

Spain.—*Instituto Nacional de Industria (INI)* bought the *Potasas de Llobregat* subsidiary of *Ercros*. *Potasas de Llobregat* includes the *Sallent* and *Balsareny* Mines. Potash mining in Spain is now Government-owned as *INI* owns all of *Minas de Potasa de Suria* and 50% of *Potasas de Subiza*, south of Pamplona, along with the government of the Province of Navarra.

Thailand.—The *ASEAN Potash Mining Co. Ltd.* was established at the beginning of the year. This company is formed to produce muriate of potash from the carnallite deposit at Bamnet Narong, Chaiyaphum, on the western edge of the Khorat-Ubol Basin. Under the system designed by *Kali und Salz AG*, the magnesium chloride will be washed away for underground injection, and the potash will be recovered by dissolution-recrystallization. Capacity is planned to be 0.6 million tons, starting up in 1995.

OUTLOOK

The U.S. Bureau of Mines recently financed an update to The WEFA Group of the 1989 BOM World Fertilizer Demand Outlook Study. The study uses a model that is an adjunct to the main WEFA model through population. This connection assumes 5 billion world population in 1987 with a population growth of 1.6% from 1988 to 1994, 1.5% from 1995 to 1998, 1.4% from 1999 to 2003, and 1.3% from 2004 to 2005. From its worldwide data base on crops it uses major crop hectares of 741.8 million hectares in 1987 increasing unsteadily to 814.3 million hectares in the year 2005. Using an increase in application rates from 78 pounds per hectare in 1987 to 83 pounds per hectare in the year 2005, the model forecasts potash worldwide consumption growing from 26.3 million tons in 1987 to 30.5 million tons in the year 2005.

This submodel divides the world into the following regions: Africa, Asia, East Europe, Latin America, North America, Oceania, U.S.S.R./CIS, and Western Europe. (See table 16.)

¹All tonnages are reported in metric tons, K₂O equivalent, unless otherwise noted.

²Fertilizer International, The British Sulphur Corp., various issues of 1991. Also Green Markets, McGraw Hill, Inc. through Oct. 1991, then Green Markets, Pike & Fischer, Inc., various issues.

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TABLE 1
SALIENT POTASH¹ STATISTICS

(Thousand metric tons and thousand dollars, unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Production	2,464	2,999	3,132	3,360	3,446
K ₂ O equivalent	1,262	1,521	1,595	1,713	1,749
Sales by producers	2,904	2,802	3,008	3,391	3,327
K ₂ O equivalent	1,485	1,427	1,536	1,716	1,709
Value ²	*\$197,700	\$240,300	\$271,500	\$303,300	\$304,527
Average value per ton of product	dollars \$67.98	\$85.75	\$90.28	\$89.46	\$91.52
Average value per ton of K ₂ O equivalent	do. \$131.73	\$168.37	\$176.74	\$176.80	\$178.20
Exports ³	926	783	945	1,016	1,256
K ₂ O equivalent	470	380	446	470	624
Value ⁴	NA	NA	NA	136,100	NA
Imports for consumption ⁵	6,706	6,964	⁶ 5,618	6,952	7,467
K ₂ O equivalent	4,073	4,217	⁶ 3,410	4,164	4,527
Customs value	\$433,000	\$623,000	\$501,300	\$545,700	\$549,600
Consumption, apparent ⁷	8,683	8,983	⁶ 7,680	8,990	9,538
K ₂ O equivalent	5,088	5,264	⁶ 4,500	5,453	5,612
Yearend producers' stocks, K ₂ O equivalent	155	248	307	303	343
World: Production, marketable K ₂ O equivalent	[†] 30,456	[†] 31,836	[†] 29,580	[†] 27,685	[†] 25,548

*Estimated. †Revised. NA Not available.

¹Includes muriate and sulfate of potash, potassium magnesium sulfate, and some parent salts. Excludes other chemical compounds containing potassium.

²F.o.b. mine.

³Excludes potassium chemicals and mixed fertilizers.

⁴F.a.s. U.S. port.

⁵Includes nitrate of potash.

⁶Imports probably under reported.

⁷Calculated from production plus imports minus exports plus or minus industry and Government stock changes.

TABLE 2
PRODUCTION, SALES, AND INVENTORY OF U.S. PRODUCED POTASH, BY TYPE AND GRADE

(Thousand metric tons and thousand dollars)

Type and grade	Production						Sold or used				Stocks, end of 6-month period				
	Gross weight		K ₂ O equivalent		Gross weight		K ₂ O equivalent		Value ¹		Gross weight		K ₂ O equivalent		
	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991	
January-June:															
Muriate of potash, 60% K ₂ O minimum:															
Standard	342	322	209	197	317	393	194	240	25,200	30,200	166	38	101	23	
Coarse	110	106	67	65	119	83	73	51	9,600	7,400	24	38	15	23	
Granular	583	622	354	378	536	777	325	471	44,000	64,000	226	86	137	52	
Chemical	9	9	5	5	8	8	5	5	W	W	2	1	1	(²)	
Potassium sulfate	207	237	105	120	226	235	115	119	37,600	37,700	63	80	32	41	
Other potassium salts ³	445	429	119	111	508	445	134	119	W	W	147	160	34	35	
Total ⁴	1,695	1,723	860	876	1,716	1,940	847	1,005	156,800	177,900	628	402	320	174	
July-December:															
Muriate of potash, 60% K ₂ O minimum:															
Standard	334	352	203	214	392	283	238	173	28,702	22,900	108	107	66	65	
Coarse	113	112	69	69	122	86	74	53	9,600	6,800	15	64	9	39	
Granular	604	600	366	363	589	478	358	289	47,100	37,700	240	208	145	126	
Chemical	5	9	3	6	7	9	4	6	W	W	(²)	1	(²)	1	
Potassium sulfate	222	215	114	109	207	180	106	92	32,600	29,800	78	115	40	58	
Other potassium salts ³	387	431	98	111	358	351	88	92	W	W	176	242	43	55	
Total ⁴	1,665	1,723	853	873	1,675	1,387	868	704	146,500	126,600	618	738	303	343	
Grand total ⁴	3,360	3,446	1,713	1,749	3,391	3,327	1,716	1,709	303,300	304,500	XX	XX	XX	XX	

¹Estimated. W Withheld to avoid disclosing company proprietary data; included in "Total." XX Not applicable.

²F.o.b. mine.

³Less than 1/2 unit.

⁴Includes soluble muriate, manure salts, and potassium magnesium sulfate.

⁵Data may not add to totals shown because of independent rounding.

TABLE 3
PRODUCTION AND SALES OF POTASH IN NEW MEXICO

(Thousand metric tons and thousand dollars)

Period	Crude salts ¹ (mine production)		Marketable potassium salts				
	Gross weight	K ₂ O equivalent	Production		Sold or used		Value ²
			Gross weight	K ₂ O equivalent	Gross weight	K ₂ O equivalent	
1990:							
January-June	7,348	1,019	1,462	729	1,450	698	123,174
July-December	7,583	1,034	1,429	721	1,468	753	122,397
Total	14,931	2,053	2,891	1,450	2,918	1,451	245,571
1991:							
January-June	8,090	1,052	1,464	733	1,682	863	145,436
July-December	8,196	1,198	1,487	741	1,213	607	105,431
Total	16,286	2,250	2,951	1,474	2,895	1,470	250,867

²Estimated.

¹Sylvinite and langbeinite.

³F.o.b. mine.

TABLE 4
SALIENT U.S. SULFATE OF POTASH¹ STATISTICS

(Thousand metric tons of K₂O equivalent and thousand dollars)

	1988	1989	1990	1991
Production	117	166	219	230
Sales by producers	109	147	221	211
Value ²	\$36,854	\$47,355	\$70,226	\$67,432
Exports ^{3 4}	91	78	124	104
Value ⁵	NA	NA	\$43	NA
Imports ³	46	32	26	29
Value ⁶	\$19,300	\$11,700	\$11,000	\$11,800
Consumption, apparent ^{4 7}	65	101	123	136
Yearend producers' stocks	23	42	39	58

²Revised. NA Not available.

¹Excluding potassium magnesium sulfate.

³F.o.b. mine.

⁴Bureau of the Census.

⁵Preliminary export data pending verification by the Bureau of the Census.

⁶F.a.s. U.S. port.

⁷C.i.f. to U.S. port.

⁸Calculated from production plus imports minus exports plus or minus industry stock changes.

TABLE 5
SALES OF NORTH AMERICAN POTASH, BY STATE OF DESTINATION

(Metric tons of K₂O equivalent)

State	Agricultural potash		Nonagricultural potash	
	1990	1991	1990	1991
Alabama	75,611	75,808	140,233	156,276
Alaska	1,756	466	26	98
Arizona	2,920	3,435	1,297	693
Arkansas	49,045	55,035	363	457
California	79,540	73,301	10,376	9,327
Colorado	12,519	11,287	844	1,753
Connecticut	1,288	999	363	516
Delaware	23,312	26,908	42,243	49,992
Florida	127,453	148,866	1,214	1,216
Georgia	116,680	133,009	1,901	1,868
Hawaii	10,213	22,346	—	—
Idaho	30,273	27,105	2,823	1,028
Illinois	514,331	518,709	2,686	10,011
Indiana	297,302	314,219	2,895	2,771
Iowa	435,537	347,002	3,966	5,307
Kansas	44,129	39,330	2,497	2,550
Kentucky	99,660	104,903	619	676
Louisiana	180,342	99,253	2,527	1,546
Maine	6,173	4,638	710	706
Maryland	28,343	26,580	422	183
Massachusetts	4,666	2,797	293	291
Michigan	150,641	170,310	8,261	6,958
Minnesota	315,495	273,820	2,443	2,810
Mississippi	43,714	43,261	42,806	46,745
Missouri	238,467	223,017	3,035	3,675
Montana	13,075	11,877	191	20
Nebraska	33,114	31,858	1,626	1,719
Nevada	749	447	26	37
New Hampshire	682	573	116	224
New Jersey	5,576	5,035	1,126	756
New Mexico	5,517	9,950	15,076	10,650
New York	59,510	51,741	19,888	720
North Carolina	78,043	100,816	1,198	669
North Dakota	21,566	21,902	15	13
Ohio	344,509	374,328	51,174	61,714
Oklahoma	20,400	16,683	4,041	2,174
Oregon	30,627	26,956	1,500	1,980
Pennsylvania	56,747	59,411	2,851	3,494
Rhode Island	1,604	709	63	38
South Carolina	59,773	52,562	122	54
South Dakota	18,464	14,587	89	99
Tennessee	102,684	90,284	1,015	454
Texas	139,697	144,426	31,765	29,007
Utah	18,607	14,451	9,115	13,914

See footnotes at end of table.

TABLE 5—Continued
SALES OF NORTH AMERICAN POTASH, BY STATE OF DESTINATION

(Metric tons of K₂O equivalent)

State	Agricultural potash		Nonagricultural potash	
	1990	1991	1990	1991
Vermont	5,987	6,898	49	132
West Virginia	8,162	13,079	564	743
Wisconsin	256,432	200,846	29,018	34,578
Wyoming	3,008	2,784	851	1,041
Total ¹	4,310,921	4,110,858	449,758	476,199

¹Data may not add to totals shown because of independent rounding.

Source: Potash & Phosphate Institute.

TABLE 6
SALES OF NORTH AMERICAN MURIATE OF POTASH TO U.S. CUSTOMERS, BY GRADE

(Thousand metric tons of K₂O equivalent)

Grade	1988	1989	1990	1991
Agricultural:				
Standard	259	310	263	251
Coarse	2,095	2,036	1,882	1,862
Granular	1,530	1,658	1,658	1,482
Soluble	339	342	334	349
Total	4,223	4,346	4,137	3,944
Nonagricultural:				
Soluble	104	116	131	85
Other	283	305	314	387
Total	387	421	445	473
Grand total	4,610	4,767	4,582	4,417

¹Data do not add to total shown because of independent rounding.

Source: Potash & Phosphate Institute.

TABLE 7
PRICES¹ OF U.S. POTASH, BY TYPE AND GRADE

(Dollars per metric ton of K₂O equivalent)

Type and grade	1989		1990		1991	
	January-June	July-December	January-June	July-December	January-June	July-December
Muriate, 60% K₂O minimum:						
Standard	129.29	123.45	129.84	120.52	126.21	132.27
Coarse	142.77	140.92	137.32	129.07	143.36	129.17
Granular	149.01	138.05	135.36	131.60	135.63	130.29
All muriate ²	140.80	132.98	133.25	124.38	133.25	130.84
Sulfate, 50% K₂O minimum						
	336.48	306.96	326.34	307.47	315.67	324.32

¹Average prices, f.o.b. mine, based on sales.

²Excluding soluble and chemical muriates.

TABLE 8
U.S. EXPORTS OF POTASH, BY TYPE

	Approximate average K ₂ O content (percent)	Quantity (metric tons)		Value (thousands)
		Product	K ₂ O equivalent	
1990:				
Potassium chloride, all grades	61	445,800	271,900	\$46,500
Potassium sulfate	51	243,700	124,300	43,300
Potassium magnesium sulfate	22	318,200	70,000	41,400
Potassium nitrate	45	7,841	3,528	5,000
Total	XX	1,016,000	469,800	¹136,100
1991:				
Potassium chloride, all grades	61	730,600	445,700	NA
Potassium sulfate	51	203,300	103,700	NA
Potassium magnesium sulfate	22	306,400	67,330	NA
Potassium nitrate	45	15,910	7,159	NA
Total	XX	1,256,000	623,900	NA

NA Not available. XX Not applicable.

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 9
U.S. EXPORTS OF POTASH, BY COUNTRY¹

(Metric tons of product)

Country	Potassium chloride		Potassium sulfates, all grades ²		Potassium nitrate		Total ³	
	1990 ^e	1991	1990	1991	1990	1991	1990 ^e	1991
Algeria	—	91	—	—	—	—	—	91
Argentina	10,380	8,873	5,230	5,456	—	—	15,600	14,330
Australia	19	36	6,960	15,840	—	3	6,976	15,880
Bahamas	—	20	80	49	—	—	79	69
Bangladesh	—	—	2,200	6,300	—	—	2,200	6,300
Barbados	82	21	—	18	—	—	82	39
Belgium	—	15,540	—	—	—	—	—	15,540
Belize	2,583	2,175	190	271	—	—	2,770	2,446
Bolivia	292	417	18	—	19	—	329	417
Brazil	162,300	297,120	4,000	11,450	—	—	166,300	308,600
Canada	6,325	7,424	87,200	67,910	4,660	4,115	98,210	79,450
Chile	12,980	17,170	18,100	23,730	—	—	31,100	40,900
China	—	54,050	105,670	122,600	—	—	105,700	176,700
Colombia	38,170	9	15,460	22,930	—	—	53,620	22,940
Costa Rica	31,730	34,020	22,310	25,620	—	—	54,050	59,640
Dominican Republic	45,570	34,420	3,160	3,987	—	—	48,730	38,410
Ecuador	17,350	21,790	13,380	7,109	10	—	30,730	28,890
Egypt	—	1,649	1,000	—	—	—	1,000	1,649
El Salvador	1,080	—	1,000	—	—	—	2,080	—
Fiji	—	—	2,090	—	—	—	2,091	—
Germany, Federal Republic of	117	168	—	—	—	—	117	168
Guatemala	—	10,610	4,400	1,581	—	—	4,409	12,190
Guyana	500	—	—	—	—	—	500	—
Honduras	9,690	16,720	90	1,575	—	—	9,781	18,300
Hong Kong	—	—	400	—	—	—	430	—
India	—	—	18,400	—	—	—	18,395	—
Indonesia	—	—	7,970	—	—	—	7,967	—
Ireland	—	6,971	—	—	—	—	—	6,971
Israel	—	—	—	511	—	1	—	512
Italy	14,850	75	16,550	11,780	—	8	31,400	11,860
Jamaica	—	5,534	—	—	—	—	—	5,534
Japan	19,140	47,760	135,000	120,280	3,060	8,415	157,300	176,500
Korea, Republic of	—	5,240	6	1,786	3	—	9	7,026
Malaysia	—	—	14,700	12,510	—	—	14,700	12,510
Martinique	8,820	5,814	4,550	3,000	—	—	13,368	8,814
Mexico	26,960	53,420	34,600	31,870	78	3,315	61,640	88,610
Netherlands	—	—	—	1,646	—	—	—	1,646
New Zealand	—	18	250	52	—	—	248	70
Nicaragua	—	3,090	—	—	—	—	—	3,090
Pakistan	—	—	29,570	—	—	—	29,573	—
Panama	7,250	8,059	1,870	265	—	—	9,118	8,324
Peru	2,000	5,725	—	2,100	—	—	1,998	7,825
Saudi Arabia	—	571	1	—	1	—	2	571
Singapore	—	—	—	2,012	—	—	—	2,012
South Africa, Republic of	—	5,499	—	100	—	—	—	5,599
Sweden	950	408	—	—	—	—	952	408

See footnotes at end of table.

TABLE 9—Continued
U.S. EXPORTS OF POTASH, BY COUNTRY¹

(Metric tons of product)

Country	Potassium chloride		Potassium sulfates, all grades ²		Potassium nitrate		Total ³	
	1990 ⁴	1991	1990	1991	1990	1991	1990 ⁴	1991
Taiwan	—	—	85	243	—	—	85	243
Thailand	—	—	5,300	5,000	—	3	5,250	5,003
Trinidad and Tobago	2,540	1,429	35	—	3	—	2,578	1,429
United Kingdom	340	13,070	—	11	—	—	341	13,080
Uruguay	2,801	—	—	—	—	—	2,801	—
Venezuela	20,950	45,510	—	20	2	35	20,950	45,570
Other	25	104	15	125	4	14	44	234
Total ³	445,800	730,600	561,900	509,700	7,840	15,910	1,015,600	1,256,300

¹Revised.

²The Bureau of the Census ceased publication of value data in 1985, but now makes value by code, by month available.

³Includes potassium magnesium sulfate.

⁴Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 10
U.S. IMPORTS FOR CONSUMPTION OF POTASH, BY TYPE

	Approximate average K ₂ O content (percent)	Quantity (metric tons)		Value (thousands)	
		Product	K ₂ O equivalent ^a	Customs	C.i.f.
1990:					
Potassium chloride	61	6,816,000	4,114,600	\$520,000	\$644,200
Potassium sulfate	51	51,900	26,400	9,500	11,000
Potassium nitrate	45	36,100	16,200	10,100	11,400
Potassium sodium nitrate mixtures	14	47,800	6,700	5,500	6,300
Total	XX	6,951,800	4,163,900	545,700	672,900
1991:					
Potassium chloride	61	7,348,700	4,482,700	528,500	634,700
Potassium sulfate	51	57,000	29,100	10,100	11,800
Potassium nitrate	45	22,300	10,000	6,000	6,900
Potassium sodium nitrate mixtures	14	39,000	5,500	5,000	5,600
Total	XX	7,467,000	4,527,300	549,600	659,000

^aEstimated. XX Not applicable.

Source: Bureau of the Census, as adjusted by the U.S. Bureau of Mines.

TABLE 11
U.S. IMPORTS FOR CONSUMPTION OF POTASH, BY COUNTRY

Country	Metric tons of product										Total value (thousands)			
	Potassium chloride		Potassium sulfate		Potassium nitrate		Potassium sodium nitrate		Total ¹		Customs		C.i.f.	
	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991
Belgium-Luxembourg	2,500	3,000	11,900	5,500	139	362	—	19	14,500	8,800	\$2,500	\$1,400	\$3,000	\$1,600
Canada	6,286,500	6,836,800	500	600	5	1	18,300	12,800	6,305,300	6,850,000	481,900	487,500	601,300	587,200
Chile	—	—	—	0	13,800	13,300	29,300	26,000	43,100	39,300	6,200	5,900	7,300	6,900
France	—	—	4,000	5,200	—	—	—	—	4,000	5,200	700	1,100	800	1,300
Germany, Federal Republic of:														
Eastern states	122,900	—	—	—	24	—	—	—	122,900	—	8,100	—	—	9,200
Western states	18,800	130,300	35,400	45,500	—	—	—	—	54,200	175,800	8,000	18,000	9,100	20,900
Israel	363,300	185,200	—	—	22,000	8,300	—	—	385,300	193,500	36,500	20,700	40,000	23,100
Italy	—	—	5	30	—	86	—	—	5	116	2	27	3	30
Japan	—	17	73	236	7	24	200	178	280	455	180	343	200	380
Mexico	—	—	—	—	1	—	—	—	1	—	1	—	1	1
Netherlands	—	—	—	—	—	3	—	—	—	319	—	33	—	39
Poland	—	—	—	—	80	218	—	—	80	218	30	89	40	111
U.S.S.R.	21,800	192,900	—	—	—	1	—	—	21,800	192,900	1,500	14,400	1,800	17,300
United Kingdom	223	211	—	—	20	—	—	—	243	211	173	125	204	143
Yugoslavia	—	—	—	—	23	—	—	—	23	—	20	—	20	—
Total¹	6,816,000	7,348,700	51,900	57,000	36,100	22,300	47,800	39,000	6,951,700	7,467,000	545,700	549,600	673,000	659,000

¹Data may not add to totals shown because of independent rounding.

Sources: Bureau of the Census, as adjusted by the U.S. Bureau of Mines.

**TABLE 12
WORLD POTASH ANNUAL
PRODUCTION CAPACITY,
DECEMBER 31, 1991, RATED
CAPACITY¹**

(Thousand metric tons of K₂O equivalent)

Country	Capacity
North America:	
Canada	11,520
Mexico	NA
United States	1,920
Total	13,440
South America:	
Brazil	150
Chile	45
Total	195
Europe:	
Commonwealth of Independent States	13,700
France	1,680
Germany, Federal Republic of:	
Eastern states	2,200
Western states	2,350
Italy	400
Spain	550
United Kingdom	490
Total	21,370
Asia:	
China	120
Israel	1,350
Jordan	840
Total	2,310
World total	37,315

NA Not available.

¹Includes capacity at operating plants as well as at plants on standby basis.

**TABLE 13
WORLD POTASH RESERVES
AND RESERVE BASE**

(Million metric tons, K₂O equivalent)

	Reserves	Reserve base ^{1 2}
North America:		
Canada	4,400	9,700
Mexico	NA	NA
United States	83	290
Total³	4,500	10,000
South America:		
Brazil	50	400
Chile	10	50
Total	60	450
Europe:⁴		
Commonwealth of Independent States	3,600	3,800
France ²	15	35
Germany, Federal Republic of:		
Eastern states	290	350
Western states	500	600
Italy ²	20	40
Spain ²	28	45
United Kingdom ²	24	30
Total³	4,400	4,900
Africa:		
Congo	—	20
Ethiopia	NA	NA
Tunisia	NA	NA
Total	—	20
Asia:		
China	320	320
Israel	54	600
Jordan	54	600
Laos	NA	20
Thailand	NA	100
Total³	400	1,500
World total³	9,400	17,000

NA Not available.

¹The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).

²Based on recent studies by U.S. Bureau of Mines, Division of Minerals Availability.

³Data may not add to totals shown because of independent rounding.

⁴The U.S.S.R. has increased the reserve base of the Upper Kama Basin to 19 billion tons. Apparently, the carnallite ores can be mined.

TABLE 14
SALIENT CANADIAN POTASH STATISTICS

(Thousand metric tons of K₂O equivalent)

	1988	1989	1990	1991
Production ¹	8,327	7,360	7,002	7,389
Domestic sales by domestic producers ¹	416	315	393	351
Exports:				
United States ¹	4,248	3,886	3,630	3,931
Overseas ¹	3,792	2,924	3,164	3,730
Imports for consumption ²	11	16	31	23
Domestic consumption ³	427	331	424	374
Yearend producers' stocks ¹	1,356	1,596	1,272	1,586

¹Data supplied by the Potash & Phosphate Institute.

²From Bureau of the Census export data. Sulfate of potash and nitrate of potash were landed on the Canadian east coast from European sources.

³Domestic sales by domestic producers plus imports.

TABLE 15
MARKETABLE POTASH: WORLD PRODUCTION, BY COUNTRY¹

(Thousand metric tons of K₂O equivalent)

Country	1987	1988	1989	1990	1991 ^a
Brazil	37	54	97	'66	² 102
Canada ³	7,668	8,154	'7,014	'7,345	² 7,012
Chile ⁴	23	25	'25	'25	20
China ^a	40	40	40	'60	60
France	1,539	1,502	1,195	'1,230	² 1,129
Germany, Federal Republic of:					
Eastern states	3,510	3,510	'3,852	'2,650	NA
Western states	2,199	2,290	2,182	'2,215	NA
Total	5,709	5,800	6,034	4,865	² 3,868
Israel	1,253	1,244	'1,273	'1,311	1,270
Italy	134	'95	'112	'51	48
Jordan	734	785	'792	'841	² 810
Spain	741	855	'741	'690	² 585
U.S.S.R.	10,888	11,301	10,200	'9,000	8,400
United Kingdom	'428	'460	'462	'488	² 495
United States	1,262	1,521	1,595	1,713	² 1,749
Total	³ 30,456	³ 31,836	² 29,580	² 27,685	25,548

^aEstimated. ^bRevised. NA Not available.

¹Table includes data available through Apr. 20, 1992.

²Reported figure.

³Official Government figures. Potash & Phosphate Institute production data are given in table 15.

⁴Data represent officially reported output of potassium nitrate product (gross weight basis) converted assuming 14% K₂O equivalent.

TABLE 16
POTASH FERTILIZER DEMAND, BY REGION

(Million tons)

Country	1981	1985	1990	1995	2000	2005	2010
Africa	0.38	0.40	0.50	0.51	0.54	0.57	0.61
Asia	2.44	3.30	4.20	4.53	4.83	5.12	5.40
East Europe	2.69	2.79	2.42	2.63	2.84	3.03	3.29
Latin America	1.87	1.67	2.08	2.23	2.43	2.63	2.85
North America	6.18	5.52	5.17	5.44	5.69	5.96	6.21
Oceania	.24	.29	.26	.28	.31	.34	.37
U.S.S.R.	4.90	6.17	6.36	—	—	—	—
C.I.S ¹	—	—	—	6.48	7.28	7.94	8.66
Western Europe	5.62	5.82	5.75	5.61	5.28	4.97	4.67
World total	24.32	25.96	26.74	27.73	29.20	30.54	32.07

¹The Commonwealth of Independent States commenced one second after midnight, Jan. 1, 1992.

Source: World Demand for Fertilizer Nutrients of Agriculture, U.S. Bureau of Mines.

PUMICE AND PUMICITE

By Wallace P. Bolen

Mr. Bolen, a physical scientist, is a graduate of the University of Virginia and has been the commodity specialist for pumice and pumicite since September 1989. Domestic survey data were prepared by Robin L. Richardson, statistical assistant; and the international production table was prepared by Virginia Woodson, international data assistant.

ANNUAL REVIEW

Production

Pumice and pumicite sold or used in the United States decreased about 10% compared with that of 1990, according to the U.S. Bureau of Mines. Apparent consumption decreased about 28% to 506,000 metric tons, a 9-year low. In 1982, consumption was 486,000 tons. Both 1991 and 1982 were economic recession years. These recessions adversely affected building activities that caused lower demand for building materials, the major use for pumice.

Domestic Data Coverage

Domestic production data for pumice and pumicite were developed by the U.S. Bureau of Mines from one voluntary, annual survey of U.S. operations. Twelve active operations contributed 100% of the sold and used quantity and value. Two of the operations did not respond to the 1991 survey. The sold and used data for these companies were estimated. Besides the 12 active operations, two pumice companies were idle. (See table 1.)

Domestic producers were Tufflite Inc., Phoenix, AZ; California Industrial Minerals Co., Friant, CA; Glass Mountain Pumice Inc., Siskiyou Co., CA; U.S. Pumice Co., Chatsworth, CA; Hess Pumice Products, Malad City, ID; Producers Pumice, Meridan, ID; Kansas Minerals Inc., Mankato, KS; Calvert Corp., Norton, KS; Copar Pumice Co. Inc., Espanola, NM; General Pumice Corp., Santa Fe, NM; Cascade Pumice

Co., Bend, OR; and Central Oregon Pumice Co., Bend, OR.

Pumice and pumicite sold and used decreased to 401,376 tons with a value of \$9.2 million. The average price of pumice fell from \$24.13 per ton to \$22.90 per ton. Oregon remained the largest source of pumice followed by, in descending order, California, New Mexico, Idaho, Arizona, and Kansas. (See table 2.)

Consumption and Uses

The most important market for pumice remained building block, consuming 65% of the total. Pumice consumed by textile laundries and abrasive uses accounted for 9% and 6%, respectively. Other uses for pumice and pumicite included adsorbents, horticultural, concrete aggregate, diluents, fillers, filter aids, insulating medium, and landscaping.

Markets and Prices

Imports in 1991 were also affected by the recession and plummeted almost 58%. Imports from Greece decreased substantially, dropping about 82% compared to that of 1990. While imports from Guatemala also fell drastically, imports from most other countries rose.

Generally speaking, imports for construction-related uses fell while imports for more specialized uses increased or were unaffected because of the recession. Exports, which are relatively minor, declined from 20,000 to 13,000 tons. (See table 4.)

Beginning with this report, the author will begin to include brief comments on

individual pumice companies operating in the United States. Eventually all companies will be reviewed, but this year only three are included because of their uniqueness. U.S. Pumice Co. produced block pumice from a unique pumice deposit in Mono County, east-central California. This pumice was sawed for use as an affective and lightweight abrasive. It was also desirable and suitable as a carved and easily movable landscaping stone. There was an especially high demand for this block pumice in Japan. Kansas Minerals and Calvert Corp. both produced a true pumicite in north-central Kansas. Because of the fine-grained nature and location of this pumice, it was well suited for specialty uses, including filter aids, adsorbents, and abrasive. (See table 3.)

OUTLOOK

Consumption of pumice is directly related to building activity, which decreased in 1991 from that of 1990. Increased demand is expected as the economy recovers but large sustained growth in pumice consumption is unlikely. Pumice and pumicite sold or used in the United States should range between 350,000 to 550,000 tons per year through the middle of this decade.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications
Mineral Commodity Summaries, annual.
Minerals Yearbook, annual.
Mineral Industry Surveys, annual.

Other Sources

Chemical Marketing Reporter (newspaper).
Industrial Minerals Magazine (London).

TABLE 1
SALIENT PUMICE AND PUMICITE STATISTICS

(Thousand metric tons and thousand dollars unless otherwise specified)

	1987	1988	1989	1990	1991
United States: Sold and used by producers:					
Pumice and pumicite	356	353	424	443	401
Value (f.o.b. mine and/or mill)	\$4,493	\$4,129	\$8,213	\$10,688	\$9,190
Average value per ton	\$12.62	\$11.70	\$19.38	\$24.13	\$22.90
Exports*	1	1	7	20	13
Imports for consumption	247	306	293	280	118
Apparent consumption ¹	602	658	710	703	506
World: Production, pumice and related volcanic materials	¹ 11,835	¹ 11,945	¹ 11,045	¹ 10,739	¹ 10,802

*Estimated. ¹Revised.

¹Production plus imports, minus exports, plus adjustments for Government and industry stock changes.

TABLE 2
PUMICE AND PUMICITE SOLD AND USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1990		1991	
	Quantity	Value	Quantity	Value
California	72	5,088	61	4,372
Idaho	31	220	37	268
Other ¹	340	5,380	303	4,550
Total	443	10,688	401	9,190

¹To avoid disclosing company proprietary data, totals for Arizona, Kansas, New Mexico, and Oregon are included with "Other."

TABLE 3
PUMICE AND PUMICITE SOLD AND USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Thousand metric tons and thousand dollars)

Use	1990		1991	
	Quantity	Value	Quantity	Value
Abrasives ¹	23	2,978	24	3,141
Concrete admixture and aggregate	15	518	16	201
Decorative and building block	292	3,470	260	2,462
Landscaping	12	1,059	W	W
Laundries	39	1,773	38	1,610
Other ²	62	890	63	1,777
Total³	443	10,688	401	9,190

W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Includes cleaning and scouring compounds.

²Includes absorbent (1991), agricultural (horticultural), diluents (1991), fillers (1991), filter aids, insulating medium, micro silica beads (1991), road construction material, (1990), roofing granules, and other unspecified uses.

³Data may not add to totals shown because of independent rounding.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF PUMICE, BY CLASS AND COUNTRY

Country	Crude or unmanufactured		Wholly or partly unmanufactured	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1990:				
Ecuador	\$8,507	\$738	7,210	\$636
Greece	229,975	3,340	279	137
Guatemala	2,220	394	204	38
Indonesia	3,235	274	3,359	296
Italy	55	18	1,200	505
Mexico	16,231	2,108	—	—
Turkey	5,889	851	389	57
Other ²	493	135	550	352
Total	266,605	7,858	13,704	2,021
1991:				
Australia	4,070	529	—	—
Cyprus	29,035	843	—	—
Ecuador	15,971	2,754	363	52
Greece	40,822	1,185	324	93
Guatemala	982	176	80	19
Italy	84	52	1,468	802
Mexico	17,891	3,305	—	—
Turkey	6,527	1,138	453	122
Other ³	76	65	162	294
Total	86,423	10,047	2,850	1,382

¹The Journal of Commerce Port Import/Export Reporting Service data.

²Includes Austria, Canada, China, the Dominican Republic, France, Germany, India, Japan, the Republic of Korea, the Netherlands, and the United Kingdom.

³Includes Austria, Canada, China, France, Germany, Hong Kong, Indonesia, Japan, the Republic of Korea, the Netherlands, Spain, Taiwan, and the United Kingdom.

Source: Bureau of the Census.

TABLE 5
PUMICE AND RELATED VOLCANIC MATERIALS: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991 ³
Argentina ³	99,093	164,300	127,853	*125,000	125,000
Austria: Trass	6,922	7,359	*8,130	*8,954	8,700
Cameroon: Pozzolan ⁴	170,000	*130,490	130,000	130,000	130,000
Cape Verde Islands: Pozzolan ⁴	43,000	53,000	53,000	53,000	53,000
Chile: Pozzolan	242,453	277,179	299,874	*305,147	300,000
Costa Rica	6,000	6,000	6,430	*6,500	6,000
Dominica: Pumice and volcanic ash ⁴	100,000	100,000	100,000	100,000	100,000
Ethiopia ⁴	*26,000	*43,000	23,000	*23,000	23,000
France: Pozzolan and lapilli	420,000	*450,000	*450,000	*336,000	400,000
Germany, Federal Republic of: Western states: Pumice (marketable)	205,000	95,000	115,000	*110,000	100,000
Greece:					
Pumice	779,885	*752,525	640,152	*600,000	600,000
Pozzolan	814,000	*350,000	*786,000	*785,000	780,000
Guadeloupe: Pumice ⁴	220,000	220,000	220,000	220,000	220,000
Guatemala: Pumice ⁴	*15,191	15,000	15,000	15,000	15,000
Iceland	58,792	65,444	56,815	*57,000	55,000
Iran	*170,000	*190,000	212,442	237,868	250,000
Italy: ⁴					
Pumice and pumiceous lapilli	725,000	730,000	700,000	725,000	725,000
Pozzolan	5,000,000	5,000,000	4,500,000	4,500,000	4,500,000
Martinique: Pumice ⁴	130,000	130,000	130,000	130,000	130,000
New Zealand	*10,000	25,003	*40,974	*98,063	100,000
Spain ³	1,053,914	909,625	*910,000	*900,000	900,000
Turkey ⁴	760,700	1,470,700	665,500	*412,500	500,000
United States (sold and used by producers)	355,600	352,900	423,800	442,848	*401,376
Yugoslavia: Volcanic tuff	423,917	407,988	*431,444	*418,123	380,000
Total	*11,835,467	*11,945,513	*11,045,414	*10,739,003	10,802,076

*Estimated. †Revised.

¹Table includes data available through May 6, 1992.

²Pumice and related volcanic materials are also produced in a number of other countries, including (but not limited to) Japan, Mexico, and the U.S.S.R., but output is not reported quantitatively, and available information is inadequate for the formulation of reliable estimates of output levels.

³Unspecified volcanic materials produced mainly for use in construction products.

⁴Reported figure.

⁵Includes Canary Islands.

QUARTZ CRYSTAL

By Joyce A. Ober

Mrs. Ober, a physical scientist with 14 years industry and U.S. Bureau of Mines experience, has been the commodity specialist for quartz crystal since 1986. Domestic survey data were prepared by Linder Roberts, statistical assistant.

Cultured quartz crystal production was unchanged, and consumption increased in 1991 from levels recorded in 1990. Production and sales of domestic lascas as feedstock for cultured quartz crystal was higher in 1991, and reported consumption was slightly lower than in 1990. The single domestic producer of lascas, the raw material from which cultured quartz crystal is produced, operated its mine to supply material to consumers. Demand for specimen-quality natural quartz continued; quartz crystal for this application is discussed in the Gem Stones chapter.

Electronic-grade quartz crystal is single-crystal silica that is free from all visible defects and has piezoelectric properties that permit its use in electronic circuits for accurate frequency control, timing, and filtration. These uses generate practically all the demand for electronic-grade quartz crystal. A smaller amount of optical-grade quartz crystal is used as windows and lenses in specialized devices, including some lasers.

More natural quartz crystal was consumed in electronic and optical applications until 1971 when cultured quartz crystal took the lead. Since that time cultured (synthetic) quartz has replaced natural crystal in practically all these applications. In 1991, synthetic quartz crystal producers consumed about 556,000 kilograms of lascas in their production, and about 1,200 kilograms of natural quartz crystal found application in electronic devices.

DOMESTIC DATA COVERAGE

The U.S. Bureau of Mines collected

domestic production and consumption data for quartz crystal through a voluntary survey of U.S. operations. Six companies responded to the canvass for the production of cultured quartz crystal, and the five active operations represented 100% of total production shown in table 1. Of the 34 operations canvassed concerning consumption of quartz crystal, 32 responded, 11 of which did not consume quartz crystal in 1990. These companies represented almost 100% of total consumption, also shown in table 1. Consumption for the nonrespondents was estimated using reported prior-year consumption levels. (See table 1.)

ANNUAL REVIEW

Legislation and Government Programs

The National Defense Stockpile contained about 642,000 kilograms of natural quartz crystal valued at about \$8.5 million. This quantity represented an excess of about 533,000 kilograms above the stockpile goal of 109,000 kilograms. During the year, quartz crystal stockpile sales amounted to about 44,000 kilograms, with a value of about \$276,000. The stockpile material, which primarily consists of large natural crystals, could be absorbed by the specimen and gem material industry. Very little, if any, of the material would be consumed in the same applications as synthetic quartz crystal.

Strategic Considerations

Natural electronic-grade quartz crystal was initially designated as a strategic and critical material after World War II.

Cultured quartz crystal was not commercially available at the time of U.S. stockpile acquisition. With the changing patterns of quartz consumption, the Federal Emergency Management Agency asked the National Materials Advisory Board to assess the requirements and related trends for stockpiling quartz. The final report was published in early 1985 and recommended changes in stockpile goals to reflect the declining dependence on natural quartz crystal.¹ The President has set the quartz crystal goal for the stockpile at 110,000 kilograms of quartz crystal.

The National Defense Stockpile contains natural quartz in several weight classes and grades, including about 13,000 kilograms of material consisting of individual crystals weighing more than 10,000 grams each. Some of the individual quartz pieces in this weight class are suitable for generating mother seeds for cultured quartz crystal production. These large pieces were acquired from Brazil because similar materials were not available from a domestic source.²

Production

Coleman Quartz Inc., Jessieville, AR, the only domestic company known to produce lascas, supplied the feed material for cultured quartz crystal from mine production. Production in 1991 was about 7% higher than that in 1990. Coleman mined only during the summer months, but processed lascas year-round. Lascas was mined, crushed, and sized. Crushed and sized material was transported to the processing plant where operators rinsed it in oxalic acid and then

in deionized water to remove external contaminants. Finally, hand sorting, drying, and examination on a light table completed the necessary processing. The material was then shipped to cultured quartz crystal producers in 45-kilogram (100-pound) bags.

Production of cultured quartz crystal was unchanged in 1991. Five companies were active. The two largest producers, Sawyer Research Products Inc. of Eastlake, OH, and Thermo Dynamics Corp. of Merriam, KS, were independent growers that produced crystal bars for domestic and foreign consumers in the crystal device fabrication industry. Motorola Inc. of Chicago, IL, produced quartz crystal for both internal consumption and the domestic device fabrication industry. P. R. Hoffman Material Processing Co. of Carlisle, PA, also reported outside sales. Bliley Electric Co. of Erie, PA, produced only for internal consumption.

These companies produced cultured quartz crystal using a hydrothermal process in large pressure vessels, known as autoclaves. Seed crystals, very thin crystals cut to exact dimensions, were mounted on racks and suspended in the upper growth region of the vessel. Lascas was loaded in an open-mesh wire basket that was placed in the bottom of the autoclave.

A solution of sodium hydroxide or sodium carbonate (the mineralizer), with additives such as lithium salts, and deionized or distilled water was used to fill the vessel to 75% to 85% of its volume. The bottom half of the growing vessel was heated to temperatures averaging between 350° C to 400° C; the temperature of the top portion is maintained at 10° C to 50° C less. At these temperatures, the solution expands and creates an internal pressure in the vessel between 10,000 and 30,000 pounds per square inch. Under these conditions, the lascas dissolves to create a solution saturated with silica.

Through convection, the saturated solution transports dissolved silica to the cooler upper half of the vessel where it becomes supersaturated, and the excess dissolved quartz deposits on the seed

crystals in the top half of the autoclave. The process continues until the growing crystals reach their desired size. The process may take 30 to 60 days, and sometimes longer.

The processing of quartz crystals for various end uses is the same whether natural or cultured crystal is used. Crystals are examined for physical defects before cutting. They are then cut, usually with diamond or slurry saws, along a predetermined crystallographic plane to a thickness slightly larger than that desired. Each wafer is inspected and diced into blanks of the desired dimensions. The blanks then progress through a series of lapping stages until they reach the final thickness; electrodes are attached and the crystals are mounted in suitable holders. The final assembly, called a quartz crystal unit, is ready for insertion into an electronic circuit.

Consumption and Uses

Consumption of lascas by the five domestic quartz crystal producers increased about 6%, from 527,000 kilograms in 1990 to 556,000 kilograms in 1991. The 21 active device-fabricating companies in 9 States consumed 8% more quartz crystal in 1991 than that in 1990. Of these companies, 13 consumed only cultured quartz crystal. One company consumed only natural quartz crystal.

Lascas and quartz crystal were used in piezoelectric, optical, and glass industries. The piezoelectric effect is achieved when a suitable electrical signal is applied to a quartz wafer or blank with appropriate electroding and the wafer then vibrates mechanically throughout the bulk of the material at a characteristic natural resonance frequency. The quartz resonators are uniquely suitable for military-aerospace and commercial bandpass filter applications that require very high selectivity or in oscillator applications that require very high stability. In addition, for many applications requiring only moderate stability, a quartz resonator offers a unique combination of high performance, small size, and low cost. Quartz resonators were used for many less

demanding applications such as providing timing signals for watches, clocks, and microprocessors in industrial, automotive, and consumer products.

The quartz wafer becomes too thin for practical use for very high frequencies (above 100 megahertz). Quartz crystal structures that use surface vibrations, in which the frequency is determined by electrode dimensions rather than wafer thickness, have become more important at these higher frequencies. These structures are called surface acoustical wave (SAW) devices. Most optical applications used quartz in the fused form as silica glass. Relatively small quantities of cultured quartz crystal were used directly for special optical considerations. Quartz's crystal properties are responsible for its uses that deal with normally polarized laser beams. Quartz retardation plates (especially quartz wave plates), Brewster windows and prisms, birefringent filters, and tuning elements are used in laser optics.

Historically, quartz crystal has been a material of strategic importance. During World War II, quartz was used principally in analog communications (e.g., in telephone multiplexing and in mobile military radios). Today, because of military emphasis on command, control, and communications (C³) surveillance and the growth of more sophisticated electronic systems, the importance of quartz crystal devices has grown. Many of the military applications are at the leading edge of technology. It has been U.S. Department of Defense policy to require that all military systems be hardened to nuclear radiation. To meet this special requirement, cultured quartz crystal must be radiation hardened by sweeping, a technique to remove certain impurities from the quartz.

Cultured quartz was used almost exclusively by the crystal device industry because of cost advantages. For resonator applications, raw quartz must be cut into thin wafers oriented precisely with the raw material crystal axes. The uniformity and convenience of cultured quartz have made its use almost universal. Unlike cultured quartz, natural electronic-grade quartz requires special

orientation, cutting, grading, and sizing to produce a quartz wafer. As a result, most device manufacturers that cut natural quartz in the past have discontinued its use. One of the remaining uses of natural electronic-grade material was in pressure transducers used in deep oil wells.

Stocks

Crystal growers' stocks of as-grown cultured quartz crystal were reported as 97,000 kilograms at the beginning of 1991. At yearend, these stocks had decreased to 89,000 kilograms.

Prices

The average value of as-grown cultured quartz, based on reported sales of about 353,000 kilograms, was \$28.04 per kilogram (\$12.76 per pound), a slight decrease compared with that of 1990. Sales volume increased about 9%. The average value of lumbered quartz, as-grown quartz that has been processed by sawing and grinding, decreased 38% to \$66.37 per kilogram (\$30.13 per pound), based on reported sales of 29,000 kilograms. Sales volume decreased 12%.

Foreign Trade

The Bureau of the Census began using the Harmonized Tariff Schedule in 1989 to identify material passing through U.S. customs. This system makes classification codes for imports and exports consistent internationally. With the adoption of the new codes, imports and export codes for quartz crystal changed, and some formerly listed details are no longer available. The import code for Brazilian crude pebble, which represented nearly all lascas imports recorded, was eliminated. Although this material probably continued to enter the United States, the new code system aggregated several categories, making information about specific materials unavailable. Likewise, the export data for natural electronic-grade quartz crystal were no longer available.

World Review

Synthetic quartz crystal production is concentrated in the United States and Japan, with several companies producing crystal in each country. Smaller production capacity exists in Belgium, Brazil, Bulgaria, France, the Federal Republic of Germany, the Republic of South Africa, and the United Kingdom. Details concerning quartz operations in China, the U.S.S.R., and other Eastern European countries is unavailable.

OUTLOOK

Domestic production of cultured quartz crystal has grown or remained relatively stable since 1986. Demand for crystal devices for electronic consumer products and microprocessor controlled devices should continue to grow, and quartz crystal production should remain strong well into the future. Because crystal devices continued to be used in an increasing variety of applications from kitchen appliances to military hardware in addition to the traditional items such as watches, demand should continue to increase and additional production capacity may be required worldwide.

¹National Materials Advisory Board. Quartz for the National Defense Stockpile. Natl. Acad. Sci., Washington, DC, NMAB-424, Jan. 1985, 99 pp.

²Work cited in footnote 1.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Quartz Crystal. Ch. in Mineral Commodity Summaries, annual.

Other Sources

Electronic Component News, monthly.
Electronic News, weekly.
Electronics, biweekly.
Industrial Minerals (London), monthly.
Mining Engineering, monthly.

TABLE 1
SALIENT U.S. ELECTRONIC-AND OPTICAL-GRADE
QUARTZ CRYSTAL STATISTICS

(Thousand kilograms and thousand dollars)

	1986	1987	1988	1989	1990	1991
Production:						
Mine ¹	544	—	272	454	423	454
Cultured	238	381	389	464	441	441
Exports:						
Natural:²						
Quantity	34	63	43	NA	NA	NA
Value	\$411	\$708	\$431	NA	NA	NA
Cultured:²						
Quantity	147	203	189	57	39	53
Value	\$5,686	\$6,954	\$7,162	\$2,600	\$1,745	\$2,620
Lascas:						
Quantity	—	—	—	—	—	—
Imports of lascas:³						
Quantity	24	66	98	NA	NA	NA
Value	\$51	\$157	\$180	NA	NA	NA
Consumption:						
Natural (electronic- and optical-grade)	1	(*)	2	(*)	(*)	1
Cultured (lumbered)	20	25	28	17	14	12
Cultured (as grown)	194	250	293	344	326	353
Total	215	275	323	361	340	366

NA Not available.

¹Excludes lascas produced for specimen and jewelry material uses.

²Bureau of the Census as adjusted by the U.S. Bureau of Mines.

³Bureau of the Census.

*Less than 1/2 unit.

RARE EARTHS

THE LANTHANIDES, YTTRIUM, AND SCANDIUM

By James B. Hedrick

Mr. Hedrick is a physical scientist in the Branch of Industrial Minerals. He has been the commodity specialist for rare earths since 1981. Domestic survey data were prepared by Kevin Bacon, statistical assistant; and international data were prepared by Harold Willis, international data coordinator.

Performance of the rare-earth industry in 1991 was weak because of a recession in the domestic economy coupled with continued competition from foreign sources. Principal foreign markets for rare earths, such as Japan, also experienced downturns in their economies. Most domestic rare-earth markets experienced a decline. Significant activity was seen from the Commonwealth of Independent States (C.I.S.) (previously the U.S.S.R.), as export restrictions on rare earths were lifted. New applications and the development of emerging markets highlighted the otherwise down year.

Domestic mine production of rare earths decreased in 1991. Significant growth was reported only in the permanent magnet sector as demand for neodymium-iron-boron magnets expanded. Traditional major rare-earth markets, petroleum cracking catalysts and metallurgical applications, were essentially unchanged from those of the previous year.

The domestic use of scandium in 1991 was small. Scandium's principal use remained lighting applications. (See table 1.)

DOMESTIC DATA COVERAGE

Domestic mine production data for rare earths are developed by the U.S. Bureau of Mines from the voluntary

survey, "Rare Earths, Thorium, and Scandium." The two mines to which a survey form was sent responded, representing 100% of known production. Production data are withheld to avoid disclosing company proprietary data.

BACKGROUND

Definitions, Grades, and Specifications

The rare earths are a group of 17 elements comprised of scandium, yttrium, and the lanthanides. Rare earths are classified chemically as members of the third subgroup of the periodic table.

Scandium, atomic number 21, is the lightest rare earth. It is the 31st most abundant element in the Earth's crust with an average crustal abundance of 22 parts per million. Although its occurrence in crustal rocks is greater than lead, mercury, and the precious metals, scandium rarely occurs in concentrated quantities as a result of its affinity to combine selectively with the common ore-forming anions.

Yttrium, atomic number 39, is chemically similar to the lanthanides and commonly occurs in the same minerals. The average concentration of yttrium in the Earth's crust is 33 parts per million and it is the second most abundant rare earth in the Earth's crust.

The lanthanides comprise a group of 15 elements with atomic numbers 57

through 71 and include: lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium. Cerium, the most abundant of the group at 60 parts per million, is more abundant than copper. Thulium, the least abundant of the lanthanides at 0.48 part per million, occurs in the Earth's crust in higher concentrations than thallium, antimony, cadmium, and bismuth.

Due largely to differing ionic radii, the rare-earth elements are broadly classified into two groups: the light rare-earth elements (LREE) or cerium subgroup, comprised of the first seven lanthanides (atomic numbers 57 through 63) and the heavy rare-earth elements (HREE) or yttrium subgroup comprised of the remaining lanthanides and yttrium (atomic numbers 64 through 71 and 39). Yttrium is classed with the heavy subgroup because of its occurrence, ionic radius, and other similar properties.

Bastnasite can theoretically contain 74.81% rare-earth oxide (REO).¹ Flotation concentrates of bastnasite average 60% REO, which can be upgraded to 70% REO by acid leaching and to 85% REO by a combination of acid leaching and calcining.

Monazite can theoretically contain 69.73% REO. Monazite concentrate is usually sold at 55% minimum REO

contained plus thorium, with product grading from 55% to 65% REO. Thorium contents are variable, but typically occur in the range of 4% to 10% equivalent thorium oxide.

Xenotime can theoretically contain 61.40% yttrium oxide. However, xenotime concentrates from Southeast Asia and Australia typically contain 25% to 30% yttrium oxide. Xenotime is often upgraded by acid leaching to produce an yttrium concentrate grading 60% yttrium oxide and the balance primarily other rare earths.

Various metallic rare-earth products are produced. The term "mischmetal" is used to denote a mixture of rare-earth elements in metallic form. It generally has the same ratio of rare-earth elements as that found in the ore and is typically 98% to 99% pure. Recently, a higher purity "battery-grade" mischmetal was produced to supply the market for rechargeable rare-earth-nickel hydride batteries.

Ferrocium is a pyrophoric alloy of mischmetal and iron. A typical ferrocium alloy contains 74% mischmetal, 23% iron, 2% copper, and 1% magnesium.

Rare-earth silicide is an alloy typically containing about one-third mischmetal, one-third iron, and one-third silicon. The rare-earth content of a silicide may be as high as 50%.

The rare-earth content of master alloys range from tenths of a percent in nodularizing alloys for ductile iron to tens of a percent in inoculants for gray cast iron. Alloys containing almost 100% rare-earth metals, such as mischmetal, are additives to certain steels.

The purity of separated rare-earth elements, produced primarily by solvent extraction or ion exchange, usually grade 96% or higher in purity. High-purity rare-earth compounds and metals are produced up to 99.9999% purity. Rare-earth products grading higher than 99.9% purity are often produced to specification. As a result of the wide range of products in which rare earths are consumed, many grades of rare-earth concentrates, compounds, alloys, and metals are produced. Analyses of the

rare-earth contents of selected ores are shown in table 2. (See table 2.)

Products for Trade and Industry

A wide variety of products is available for trade and industry, including concentrates, individual and mixed compounds, and pure and alloyed metals.

Bastnasite concentrate from a domestic source is available in three grades, an unleached concentrate grading 60% REO, an acid-leached concentrate containing 70% REO, and a calcined concentrate upgraded to 85% REO.

A mixed bastnasite-monzazite concentrate (predominately bastnasite) from China is produced in three grades, a 30% minimum REO, a 60% minimum REO, and a 71% minimum REO.

Mixed compounds derived from bastnasite include rare-earth chloride, rare-earth nitrate, lanthanum-rare-earth carbonate, lanthanum carbonate, cerium carbonate, cerium nitrate, cerium fluoride, neodymium carbonate, neodymium fluoride, praseodymium fluoride, cerium-rare-earth hydrate, and rare-earth hydrate.

Monazite is marketed by processors and trading firms as a concentrate containing 55% to 60% minimum REO plus contained thorium. Mixed compounds produced from monazite include cerium chloride, ceric ammonium nitrate, ceric sulfate, cerium carbonate, cerium hydroxide, cerium nitrate, cerium octoate, rare-earth carbonate, lanthanum carbonate, lanthanum-neodymium carbonate, lanthanum-neodymium nitrate, neodymium carbonate, neodymium nitrate, praseodymium oxalate, rare-earth octoate, and yttrium nitrate.

Xenotime concentrate with a minimum 25% yttrium oxide content is a major source of yttrium. It is usually upgraded chemically to a 60% yttrium oxide product known as yttrium concentrate, the balance of the concentrate being mostly other rare earths. The primary product derived from yttrium concentrate is high-purity yttrium oxide.

Rare-earth ion adsorption ore is produced in southern China. It is also a major source of yttrium. The ore varies

by locality, but the two principal concentrates are an yttrium concentrate and a europium concentrate. The yttrium concentrate is enriched in heavy-rare earths and grades greater than 60% yttrium oxide. The europium concentrate grades from 0.5% to 1% europium oxide, 12% yttrium oxide, but is predominantly enriched in lanthanum oxide, 33% to 43%. Both ion adsorption concentrates are low in cerium oxide, typically less than 2%.

Individual rare-earth oxides and other compounds, except promethium, are produced from bastnasite, monazite, xenotime, and ion adsorption ore. Purities from 96% up to 99.9999% are available for most oxides. Compounds for almost all of the rare earths are available as oxides, acetates, carbonates, chlorides, fluorides, nitrates, oxalates, and sulfates.

High-purity rare-earth metals are marketed in the form of sponge, lump, ingot, rod, wire, chips, powder, sheet, foil, plate, sputtering plates, and custom cast and machined shapes. Alloys such as mischmetal, rare-earth silicide, ferrocium, and other rare-earth alloys are available in a variety of ingot shapes and sizes.

Rare-earth magnet alloys are produced in a variety of compositions to meet individual requirements. Magnet alloys are marketed in ingot form, crushed ribbon, or may be purchased as mixed oxides for powder metallurgical processes. Magnets are available in finished and semifinished shapes, bonded and unbonded, magnetized and unmagnetized, and either coated or uncoated.

Scandium concentrate previously was produced as a byproduct during uranium extraction and from tailings remaining from a previously operated fluorite operation. Scandium is marketed primarily as a high-purity oxide. Oxide purities from 98% to 99.9999% have been produced in the United States. In addition to the oxide, scandium compounds are available as the acetate, bromide, carbonate, chloride, fluoride, hydride, iodide, nitrate, oxalate, acetylacetonate, and sulfate. Scandium

metal is produced in ingot, powder, lump, and foil form.

Industry Structure

Few companies in the rare-earth industry are fully integrated. Rare earths are typically mined and processed by different companies. In the United States, MolyCorp, Inc., is the only fully integrated producer from its mine at Mountain Pass, CA. The other domestic producer, in Florida, operates a mine with wet and dry mill concentrators.

Rare-earth ore is beneficiated by mine producers into concentrates that are sold directly to processors or, to a lesser extent, are sold to brokers for resale.

Rare-earth concentrates undergo extensive processing to produce mixed and separated compounds. The major processes used in separating rare earths are precipitation, solvent extraction, and ion exchange. Processors sell refined rare-earth products directly to consumers or brokers.

The scandium industry, for the most part, is separate and distinct from the lanthanide and yttrium industry. Its high price and very limited demand have made scandium one of the smallest commodity markets in the world. As with lanthanides, the scandium industry is rarely fully integrated. Due to limited demand, scandium is not currently mined in the United States. Byproduct mine production is presently only from China and the C.I.S. Although minor amounts of scandium are separated from lanthanide and yttrium ores, most scandium is produced as a byproduct from other ores.

In the United States, scandium has been recovered as a byproduct during processing of byproduct uranium at a copper mine, from tailings from a mined-out fluorite mine, and from tungsten byproduct from a molybdenum operation. Tailings and concentrates from these sites were shipped to processors for production of high-purity scandium oxide and other compounds. Three processors in the United States refine scandium oxide. Scandium is also refined in China, the C.I.S., Norway,

and the United Kingdom. Most scandium is sold in oxide form. Metal production is often effectuated by a small group of separate companies, primarily for research purposes.

Geology-Resources

Rare-earth minerals occur in a variety of geologic environments. Concentrations exist in igneous, sedimentary, and metamorphic rocks. The rare earths are mined primarily from igneous and sedimentary deposits.

The rare earths are constituents in more than 100 minerals, but only a few are recovered. Bastnasite, monazite, xenotime, and rare-earth-bearing clay are the principal sources of the world's rare-earth supply. Other sources are loparite, uraniferous phosphorites, synchisite, and byproduct solutions from processing uranium. Future production may include rare earths recovered from the minerals cheralite, secondary monazite, rhabdophane, cerianite, florencite, churchite, gadolinite, and eudialyte.

Bastnasite.—Bastnasite, a rare-earth fluorocarbonate, is found in vein deposits, contact metamorphic zones, pegmatites, and carbonatites. It is typically enriched in the LREE (bastnasite-Ce), however a rare HREE variety (bastnasite-Y) is found in Kazakhstan, C.I.S. Bastnasite forms in the trigonal crystal system and ranges in color from yellow to reddish-brown. It has the following mineralogical properties: transparent to translucent; vitreous to greasy luster; density of 4.78 to 5.2 grams per cubic centimeter; and a Mohs' hardness of 4 to 4½.² It forms as an igneous or hydrothermal mineral and occurs as an accessory mineral in several large deposits. Deposits containing bastnasite as a high-grade accessory mineral are at Mountain Pass, CA, United States; Bayan Obo, Nei Monggol Autonomous Region, China; Wigu Hill, Tanzania; and Karonge, Burundi.³ Bastnasite and other independent rare-earth minerals commonly form by hydrothermal processes, although its occurrence at Mountain Pass, CA, is

considered primary igneous. Concentration of the rare earths can occur in nature as a result of coprecipitation with calcium carbonate or by precipitation in the presence of fluorine. While the Mountain Pass bastnasite is believed to have formed by the coprecipitation process, the Bayan Obo bastnasite is hydrothermal in origin and formed by alteration of dolomite in the presence of large amounts of fluorine.⁴ Most of the world's rare-earth resources are recovered from bastnasite.

Monazite.—Monazite, a rare-earth phosphate, is one of the most abundant rare-earth minerals, and it is the world's second leading source of rare earths. Monazite occurs as an accessory mineral in granitic and metamorphic rocks, pegmatites, vein deposits, as a detrital mineral in placer deposits, and as a hydrothermal and supergene mineral in carbonatites. It is classified as a LREE and is usually enriched in cerium (monazite-Ce). Rarer monazite varieties are a lanthanum-rich monazite (monazite-La) and a neodymium-rich monazite (monazite-Nd) found in Italy and from Marmara, Greece.⁵ Monazite, which forms as a monoclinic mineral, is found in a wide range of colors, including honey yellow, greenish brown, reddish brown, yellowish brown, brown, pink, yellow, grayish white, dark gray, and black. It has the following mineralogical properties: transparent to subtranslucent; resinous, waxy, vitreous, or subadamantine luster; density 4.6 to 5.4 grams per cubic centimeter; and a Mohs' hardness of 5 to 5½.⁶ Monazite forms primarily as an accessory mineral in igneous and metamorphic rocks, including granites, gneisses, aplites, and pegmatites, and occasionally as a vein mineral (VanRhynsdorp, Republic of South Africa).

Economic placers develop where monazite has been weathered from its original host rock and concentrated by wind and water. Placer monazite is mined as a byproduct of titanium and zirconium minerals or tin minerals. Significant placer deposits are in

Australia, Brazil, Malaysia, Thailand, and the United States.⁷

Monazite of hydrothermal and supergene origin in carbonatites also represents a large rare-earth resource. Deposits of this type occur at Araxá, Minas Gerais, Brazil; Catalao I, Goiás, Brazil; Bayan Obo, Nei Monggol Autonomous Region, China; and Mount Weld, Western Australia, Australia.⁸

China's Bayan Obo deposit is known primarily as the world's largest bastnasite deposit; however, it contains substantial tonnages of monazite. Formed by hydrothermal alteration of dolomite, the Bayan Obo monazite occurs in veins and stockworks in the footwall rocks.⁹

One of the richest grade rare-earth deposits in the world is the Mount Weld carbonatite, grading 15 million metric tons at 11.2% REO, including a 1.3-million-ton zone at 23.6% REO.¹⁰ Enriched by supergene solutions, the deposit's primary ore minerals are secondary monazite and cheralite, along with lesser amounts of monazite, rhabdophane, cerianite, florencite, and churchite.

Technology

Exploration.—Exploration for rare-earth minerals (primarily thorium) began in the 1880's, for the purpose of locating thorium and cerium for incandescent gas mantles. After electric lighting came into general use about 1912, demand for gas mantles fell. Subsequently, most rare-earth deposits have been located during the search for other minerals, especially ilmenite, rutile, zircon, uranium, and gold.

Exploration techniques to locate rare earths include surface and airborne reconnaissance with magnetometric, electromagnetic, and radiometric equipment. Other methods used include satellite imagery, various types of aerial photography, and remote sensing. The application of geologic principles to develop depositional models is also applied to locate rare-earth deposits. After identifying a match for a depositional model, a surface study of the area would follow. The surface study is

typically composed of a literature and background search; geologic mapping; rock, soil, and gas sampling; geophysical testing; surface radiometric surveying; geochemical testing of water, rocks, and plants; and data analysis.

Following an acceptable surface study, a systematic subsurface sampling program would be conducted to determine ore grades and individual rare-earth contents.

Because many rare-earth minerals are associated with radioactive elements and minerals, several rare-earth deposits were discovered during exploration for uranium and thorium. Prospectors searching for radioactive minerals discovered the Mountain Pass, CA, bastnasite deposit.

Most monazite-bearing heavy-mineral deposits were discovered by exploring for recent and ancient alluvial deposits with radiometric and magnetometric equipment. Discoveries of buried alluvial deposits are typically located by depositional modeling.

Mining and Beneficiation.—Bastnasite is mined domestically as a primary product from a hard-rock carbonatite. The carbonatite is mined via bench-cut, open pit methods. Ore is drilled and blasted, loaded into trucks by rubber-tired loaders, and hauled to the mill. At the mill the blasted ore is crushed, screened, and processed by flotation to produce a bastnasite concentrate.

In China, bastnasite and lesser amounts of associated monazite also are mined from a hard-rock carbonatite. The ore is recovered as a byproduct of iron ore mining by hard-rock, open pit methods. After primary crushing at the mine site, the ore is transported by train 135 kilometers southeast to the mill because of the scarcity of water at the mine site. After separation from the iron ore by flotation, a bastnasite concentrate and a mixed bastnasite-monzazite concentrate are produced.

Heavy-mineral sands are the source of most monazite and xenotime mined in the world. Most of these minerals are recovered by surface placer methods from unconsolidated sands. Almost all mining of these sands is done by floating cutterhead or bucket wheel dredges that

concentrate the heavy minerals ("heavies") onboard and discharge the unwanted tailings back into previously mined areas. An onboard wet mill separates the "heavies" (specific gravity greater than 2.9) from the lighter weight fraction through a series of wet-gravity equipment that includes screens, hydrocyclones, spirals, and cones.

Consolidated and partially consolidated sand deposits that are too difficult to mine by dredging are mined by dry methods. Ore is stripped by typical earth-moving equipment with dozers, scrapers, and loaders. Sand recovered by these techniques is crushed and screened and then processed by the wet mill equipment previously described.

Wet mill mixed heavy-mineral concentrate is sent to a dry mill to separate the individual heavy minerals and produce a concentrate. Dry mill processing includes a combination of scrubbing, drying, screening, electrostatic, electromagnetic, magnetic, and gravity processes. Monazite, in contrast to ilmenite, rutile, and many other heavy minerals, is nonconductive and can be separated, with zircon, by electrostatic methods. Monazite, which is moderately susceptible to induced magnetism and may be slightly higher in specific gravity, can be separated from zircon by electromagnets or by additional gravity methods. Xenotime, which has a specific gravity and magnetic properties similar to monazite, is usually separated from monazite by precise gravity methods. Certain deposits also require acid-leach treatment and calcining to eliminate iron oxide or other grain coatings.

Economic Factors

Prices.—Time-price relationships for bastnasite and monazite concentrates, based on 1991 constant dollars, are shown in table 3. Price trends for bastnasite and monazite concentrate are shown in figures 1 and 2, respectively.

Concentrates of bastnasite and monazite traditionally have been low priced. Significant value is added when the concentrates are separated into the

individual rare-earth oxides or other compounds. Mischmetal prices have also been historically low, with prices remaining in the \$7 to \$12 per kilogram range over the past 20 years. Individual high-purity metals have commanded the highest prices of the rare-earth products. Metal prices typically run from two to six times the separated rare-earth oxide price.

Initially available in 1954, bastnasite concentrate was priced at \$3.31 per kilogram. By the early 1960's, the development of the first significant commercial applications for the rare earths caused its price to drop to less than \$0.50 per kilogram. Bastnasite prices have increased progressively since that time, doubling in price between 1974 and 1980 as a result of the domestic energy crisis and inflation.

Monazite pricing is more complex than that of bastnasite. As a byproduct, the supply and price of monazite is partially dependent on production and demand of the primary minerals. As a result of Australia's dominant position as a monazite producer, fluctuations in monazite's domestic price are also based on United States-Australian foreign exchange rates. Monazite's historical price trend, shown in table 3, shows an overall increase in price through 1985. In the 1950's, its price ranged from \$0.33 to \$0.40 per kilogram of REO, decreasing to \$0.22 to \$0.33 per kilogram in the early 1960's. By the mid-1960's, monazite's price began to increase steadily, with a major increase appearing in 1985, the result of a weak Australian economy and increased competition for monazite supplies. Balanced supply and demand was shown in monazite's price stability through 1990. In 1991, however, a decline in monazite's price signaled an oversupply, which was the result of the availability of low-cost separated rare earths from China, a downturn in the U.S. economy, and decreased domestic demand.

(See figures 1 and 2.)

Costs.—Mine and mill operating costs to produce bastnasite and monazite in the United States are withheld to avoid disclosing company proprietary data.

The cost to mine bastnasite is higher than that for monazite. Bastnasite, as a primary product, incurs all costs of production, whereas monazite, as a byproduct, is responsible for only a fraction of the costs. The cost to recover monazite is based almost entirely on the expenses incurred to recover the primary minerals. Mine production costs for bastnasite are also higher than monazite's because of the type of deposit. Costs to mine a hard-rock deposit (bastnasite) are significantly higher than mining a placer deposit (monazite).

Because both domestic mines have been in production for several years, mining costs are related to direct costs, which include labor, mining equipment (trucks, drills, loaders, dredges, pumps, etc.), supplies (explosives, drill bits, etc.), and utilities (fuel, natural gas, water, and electricity).

Costs to comply with environmental regulations, including waste treatment and disposal, water purification, systems monitoring, and reclamation, have continued to increase.

Tariffs.—U.S. tariff rates, specific to the rare earths, including scandium and yttrium, are shown in table 4. The duties reflect results from the 1979 Tokyo Round of Multilateral Trade Negotiations under which the tariffs on many items were reduced in several stages over the period January 1, 1980, to January 1, 1987. Tariffs are expected to remain at the present rates until new negotiations are completed. (See table 4.)

Depletion Provisions.—Depletion is the exhaustion of mineral or oil and gas reserves by mining or drilling of wells and the resulting production from these mines or wells.¹¹ Depletion allowance is a tax deduction that may be taken against income provided by the U.S. Internal Revenue Code to compensate mining companies in the United States for decreasing capital brought about by production. The allowance is based on gross income.

There are two ways of figuring depletion—cost depletion and percentage

depletion.¹² Cost depletion is usually figured by dividing the adjusted basis of the mineral property by the total number of recoverable units, and multiplying by the number of units sold during the tax year.

Percentage depletion is a certain percentage, specified for each mineral, of the gross income from the mineral property during the tax year. The depletion deduction may not be more than 50% of the taxable income from the property figured without the deduction.

The percentage depletion allowance for monazite is 22% on the thorium content and 14% on the rare-earth content when mined from domestic deposits and 14% on the thorium content and 14% on the rare-earth content from foreign deposits.

Bastnasite's depletion allowance is 14% on the rare-earth content on both domestic and foreign production.

Operating Factors

Toxicity.—The rare earths are considered only slightly toxic.¹³ However, the production of skin and lung granulomas after exposure to oxides, fluorides, chlorides, and metals by prolonged breathing, intradermal injection, or subcutaneous implantation requires extensive protection to prevent exposure through cuts and abrasions of the skin and by inhalation. Symptoms of toxicity include writhing, ataxia, labored respiration, walking on the toes with arched back, and sedation. Research has shown that males are less susceptible than females to the toxic effects of rare earths. Extreme care must also be taken when exposed to finely divided rare-earth metals and metallic powders to avoid pyrophoric burns from rapid and possibly instantaneous oxidation, especially if inhaled. Certain finely divided rare-earth metals, alloys, and powders may also present the additional hazard of oxidizing rapidly enough to explode.

It should also be noted that rare earths often exist in ore and concentrates in association with other elements that have vastly different properties, including lower and higher toxicities, and sometimes radiological hazards. Care

should be taken to assess the health factors associated with each substance present.

Employment.—Rare-earth mine and mill employment statistics, based on the quarterly average number of employees on site, are shown in figure 3. Data were furnished by the U.S. Department of Labor and compiled by the U.S. Bureau of Mines. (See figure 3.)

Productivity Trends.—The 11-year trend for U.S. rare-earth mine productivity, based on capacity utilization for bastnasite concentrate and monazite concentrate, are shown in figures 4 and 5. (See figures 4 and 5.)

Decreased bastnasite production in 1991 changed its previous 11-year trend from a slight increase to a decrease.

The 11-year trend for domestic monazite capacity utilization exhibited a decrease. However, monazite's decrease, because it is a byproduct of titanium and zirconium minerals, is primarily a function of demand for the primary products.

ANNUAL REVIEW

Legislation and Government Programs

The calendar year 1991 included the U.S. Government fiscal years for 1991 and 1992. Public Law 101-189, the National Defense Authorization Act for Fiscal Years 1990 and 1991, covered the first 9 months of 1991 and continued the authorization for disposal of all stocks in the National Defense Stockpile (NDS) classified as excess to goal, including rare earths. Stocks of rare earths in sodium sulfate classified as excess to goal at yearend 1991 were 457 tons (504 short tons). In the last 3 months of 1991, Public Law 102-190, the National Defense Authorization Act for Fiscal Years 1992 and 1993, did not continue authorization to dispose of rare earths from the stockpile.

Issues

Development of the Pajarito project, a joint venture of Molycorp and the Mescalero Apache Tribe, was suspended pending an improvement in prices for yttrium and zirconium. Economic factors stalling the project were the availability of low-cost imported yttrium, primarily from China, and decreased demand for zircon and zirconium resulting from substitution in the late 1980's, a period when market prices skyrocketed. The Pajarito deposit is on the Mescalero Reservation in southeastern New Mexico and contains yttrium and zirconium in the silicate mineral, eudialyte.

Associated Minerals (USA) Inc. changed its name to RGC (USA) Minerals Inc. in an effort to unify the company under its parent company's name, Renison Goldfields Consolidated Ltd. (RGC).

RGC Minerals, as part of an environmental rehabilitation project at its Green Cove Springs operations in Florida, planted 500,000 slash pine and 14,000 native hardwoods on 300 hectares in 1991. More than 1 million trees reportedly have been planted on 730 hectares since the mine began operating. RGC Minerals also maintained the Seminole Forest Wildlife Refuge, a 930-hectare tract near the Green Cove Springs mining site.

RGC Minerals and its parent company continued to study three heavy-mineral sands deposits, two in North Carolina and one in Virginia. The principal deposit is the Old Hickory, near Stony Creek, VA. A \$10 million feasibility study, approved in 1990, proceeded during the year. Development of the Old Hickory deposit is not expected to proceed until demand for titaniferous feedstocks and zircon improves.

Production

Two domestic mines produced rare-earth concentrates. The United States was the world's largest producer of rare earths in 1991. Producers were Molycorp, a wholly owned subsidiary of Unocal Corp., and RGC Minerals, a

wholly owned subsidiary of the Australian company, RGC.

Bastnasite was mined by open pit methods by Molycorp at Mountain Pass, CA. Molycorp's mine was the leading producer of rare earths in both the United States and the rest of the world. Mine production decreased from the previous year's level of 22,713 tons REO¹⁴ to 16,465 tons REO.¹⁵ Molycorp reportedly increased production efficiency of its high-purity lanthanide operations.

Monazite was produced as a byproduct of titanium and zirconium minerals production by RGC Minerals. Associated Minerals operated a placer dredging operation at Green Cove Springs, FL.

Reactive Metals and Alloys Corp. (REMACOR), the only domestic producer of mischmetal, operated reduction furnaces at West Pittsburg, PA.

Principal domestic producers of neodymium-iron-boron magnet alloys were the Delco Remy Div. of General Motors, Anderson, IN; Molycorp, York, PA; Neomet Corp., West Pittsburg, PA; and Rhône-Poulenc Basic Chemicals Co., Phoenix, AZ. Leading U.S. producers of rare-earth magnets were Delco Remy, Anderson, IN; Hitachi Magnetics, Edmore, MI; Crucible Materials, Elizabethtown, KY; and IG Technologies, Valparaiso, IN.

Consumption and Uses

Domestic rare-earth processors consumed 23% less rare earths in 1991 than they consumed in 1990. Bastnasite consumption was 15% lower than that in 1990, while monazite consumption decreased 10%. Shipments of rare-earth products from domestic processors of ore, concentrates, and intermediate concentrates was equivalent to 13,753 tons of REO, up 6% from the 12,975 tons shipped in 1990.

Consumption of mixed rare-earth compounds increased 10% from the 1990 level, while consumption of purified compounds decreased 16%. Higher consumption of purified compounds was primarily the result of continued strong demand for neodymium-iron-boron magnets.

The producers of mischmetal, rare-earth silicide, and other rare-earth alloys consumed 35% more rare earths in 1991 than in 1990, while shipments of these goods gained 47% during the same period. Shipments of high-purity rare-earth metals decreased 11% during the year.

The approximate distribution of rare earths by use, based on information supplied by primary processors and some consumers, was as follows: catalysts in petroleum, chemical, and pollution control, 34%; metallurgical uses as iron and steel additives and as alloys, 22%; ceramics, glass polishing compounds, and glass additives, 33%; and miscellaneous uses in phosphors, electronics, permanent magnets, lighting, and research, 11%.

Rare earths are used in hundreds of applications, ranging from 19th century traditional applications to modern high-technology uses. The applications encompass a wide range of products from mixed rare-earth compounds and metals to ultrahigh-purity products. Quantities vary by application and range from tonnage quantities to milligrams.

The following listing of uses by rare earth includes metals, alloys, oxides, and inorganic and organic compounds:

Scandium.—Metal halide lamps to improve color appearance and produce high output, laser crystals (GSGG), aluminum alloys, dual-anode tube in X-ray spectrometers, analytical standards, tracer material, and collimators in neutron lenses.

Yttrium.—High-temperature superconductor (YBaCuO), incandescent lamp mantle, phosphor for cathode-ray tubes (reddish orange), trichromatic fluorescent lighting phosphors (reddish orange), metal halide lamp phosphor (reddish orange), high-temperature sensing phosphor, oxygen sensor ceramic, laser crystal (YAG, YLF), gemstone simulants (CZ and YAG), microwave ferrites (YIG), cast iron alloys, magnesium castings, superalloys, dispersion strengthened nickel and titanium alloys, aromatization of

n-hexane, prostheses, stabilizer for silicon nitride and zirconia ceramics, microwave filters, semiconductors, acetylene lights, deoxidizer for vanadium and other nonferrous metals, solid oxide fuel cell electrolyte and anode, refractory crucibles and coatings, and high-temperature furnace electrodes.

Lanthanum.—Petroleum fluid cracking catalyst, glass additive to increase refractive index and decrease dispersion (eyeglasses, cameras, binoculars, rifle scopes, and telescope lenses), nickel hydride rechargeable batteries, hydrogen storage alloys, optical glass, solid oxide fuel cell cathode and interconnect, trichromatic fluorescent lighting phosphor (green), X-ray intensifying screen phosphors (violet, blue, yellow-green, and blue green), low-temperature sensing phosphor, phosphor lamp coating, laser glass, calcium lighting, lighting electrode, tungsten welding electrode, cast iron alloys, steel alloys, superalloys, aromatization of n-hexane, fluoride determination, conductive ceramic heating elements (chromites), dielectric ceramic capacitors (titanates), electrooptical ceramics, oxidative dimerization of methane to ethylene, antiseptic, electronic thermoemissive cathode (boride), insulation, reducing agent to convert nitrogen oxides to nitrogen, low-temperature superconductor, cryogenic refrigerant using hydrogen (LaNi₅), and semiconductors (LaAs, LaSb, LaP).

Cerium.—Glass, metal, and gemstone polishing, radiation shielding glass, glass colorization and decolorization, discolorization stabilizer, photochromic glass opacifier, ceramic pigment, ceramic glaze, enamel opacifier, carbon arc lighting, incandescent lamp mantle, trichromatic fluorescent lighting phosphor (yellow green), pyrophoric alloys including lighter flints, cast iron alloys, steel alloys, aluminum alloys, magnesium alloys, superalloys, automotive catalytic converter monolith, heat stabilizer in alumina catalyst, fluid cracking catalyst,

hydrolysis of phosphoric acid esters, oxidation of naphthalene, polymerization catalyst for olefins, corrosion inhibitor, getter in azide manufacture, getter in vacuum tubes, developing agent for aniline black, heavy metal soaps for lubricating greases and flattening agents, waterproofing and mildewproofing, dyeing and printing of textiles, ceramic capacitors, semiconductors, cathodes, desulfurizing catalysts, high-strength glass, catalyst for ammonia production, illuminant in photography, radiation dosimeter, diluent in plutonium nuclear fuels, fluorinating agent, oxidant for organic compounds, antiknock fuel additive, and pharmaceutical for sea sickness and morning sickness.

Praseodymium.—Ceramic pigment (yellow), glass colorization (light green), refractory ceramic heating element, laser crystal, aluminum alloys, magnesium alloys, permanent magnets, oxidative dimerization of methane to ethylene, and cryogenic refrigeration (PrNi₅).

Neodymium.—Permanent magnets (NdFeB), glass colorization (violet), glass decolorization, dopant in laser crystals and glass, ceramic capacitors, ceramic glaze (pinkish-violet), magnesium alloys, welder's protective glass, carbon arc lighting electrodes, catalyst for polymerization of olefins, and fiber-optic temperature sensor.

Promethium.—Fluorescent lighting starter, coatings for self-luminous watch dials, beta particle source for thickness gauges, miniature atomic batteries, semiconductor battery, X-ray source (Pm-147), and tungsten cermet for space power systems.

Samarium.—Permanent magnets (SmCo), dopant in laser crystals, neutron absorber, nuclear reactor control rod, catalyst in dehydrogenation of ethyl alcohol, catalyst in oxidative dimerization of methane to ethylene, and infrared absorbing glass.

Europium.—Cathode-ray tube phosphor (reddish-orange), trichromatic fluorescent phosphors (reddish-orange and blue), X-ray intensifying screen phosphor (violet), metal halide lamp phosphor (reddish-orange), high- and low-temperature sensing phosphors, nuclear reactor neutron absorber, nuclear reactor control rods, ceramic sensor, organic shift reagent in nuclear magnetic spectroscopy, dopant in laser crystals, and tagging agent in postage stamp glue.

Gadolinium.—Trichromatic fluorescent lighting phosphor (yellow-green), X-ray intensifying screen phosphor (yellow-green), nuclear reactor control rods, nuclear reprocessing, neutron absorbing paint, high refractive index glass, synthetic garnet for computer memory (GGG), scavenger for oxygen in titanium production, dielectric ceramics, laser crystal, cryogenic refrigeration, pharmaceutical isotope to allow scanning devices to detect osteoporosis (Gd-153), and magneto-optical recording.

Terbium.—Trichromatic fluorescent lighting phosphor (yellow-green), X-ray intensifying screen phosphors (yellow-green, violet, and blue), magnetostrictive alloys for transducers (TbFeNi), and dopant in laser crystals.

Dysprosium.—Permanent magnet addition (NdFeB), nuclear reactor control rods, semiconductors (DyAs, DySb, DyP), measurement of neutron flux, atomic weight determination, and high-temperature sensing phosphor.

Holmium.—Dopant in laser crystal, getter in vacuum tubes, and refractories.

Erbium.—Fiber-optic amplifier, glass colorizing of crystal and glassware (light pink), additive for colorization and nonreflective coating for sunglasses, infrared-absorbing glass, colorization of simulant gemstones, lasers, burnable poison in nuclear reactor, chemical catalyst for n-hexane, and permanent magnet additive.

Thulium.—X-ray source (Tm-170), dopant in laser crystal, ferrites.

Ytterbium.—Portable X-ray source for blood irradiation, dielectric ceramics, carbon rods for industrial lighting, dopant in synthetic garnet, dopant in laser crystal, and additive in special glass.

Lutetium.—High-temperature sensing phosphor and nuclear technology.

Stocks

U.S. Government stocks of rare earths in the NDS remained at 457 tons throughout 1991. Rare-earth stocks held in the stockpile were contained in sodium sulfate and were inventoried on a contained-REO basis. Rare-earth stocks in the NDS were all classified as excess to goal.

Industry stocks of rare-earth ores and concentrates held by 18 producing, processing, and consuming companies increased 25%. Bastnasite concentrate stocks held by the principal producer and three other processors increased 51% from the 1990 level. Yearend stocks of monazite decreased 24%.

Stocks of mixed rare-earth compounds increased 27%, as stocks of purified compounds increased 7%. Yearend stocks of mischmetal, rare-earth silicide, and other alloys containing rare earths gained 15%, as inventories of high-purity metals were up 79%.

Prices

Published prices for the rare earths were generally nominal and subject to change without notice. Competitive pricing policies remained in effect in 1991 with prices for most rare-earth products quoted only on a daily basis.

The price range of Australian monazite (minimum 55% REO, including thoria, f.o.b.),¹⁶ as quoted in Australian dollars (A\$),¹⁷ decreased from A\$800 to A\$900 per ton at yearend 1990 to A\$650 to A\$700 per ton at yearend 1991. Changes in the United States-Australia foreign exchange rate in 1991, resulting from a

slightly weaker Australian dollar, caused the corresponding U.S. dollar to be up \$0.02 against the Australian dollar at yearend. The U.S. price range, converted from Australian dollars, decreased substantially from US\$618 to US\$695¹⁸ per ton in 1990 to US\$494 to US\$532¹⁹ per ton in 1991.

Prices quoted by Molycorp for unleached, leached, and calcined bastnasite in standard quantities, containing 60%, 70%, and 85% REO, were \$2.87, \$2.98, and \$3.42 per kilogram (\$1.30, \$1.35, and \$1.55 per pound) of contained REO, respectively, at yearend 1991. The price for each grade of concentrate was unchanged from last year's quote.

The price of cerium concentrate quoted by American Metal Market was \$5.07 per kilogram (\$2.30 per pound) of contained cerium oxide at yearend 1991, an increase of \$0.75 from that of the previous year. The yearend price of lanthanum concentrate was unchanged from the 1990 level of \$3.09 per kilogram (\$1.40 per pound) of contained REO.

The nominal price for basic neodymium-iron-boron alloy, compiled by the U.S. Bureau of Mines, was \$22.60 per kilogram (\$10.25 per pound) at yearend, f.o.b. shipping point, 1,000-pound minimum.

Molycorp quoted prices for lanthanide (rare earth) and yttrium oxides, net 30 days, f.o.b. Louviers, CO, Mountain Pass, CA, or York, PA, effective June 1, 1991, and through the end of the year. (See table 5.)

Molycorp also quoted prices for lanthanide (rare earth) compounds, net 30 days, f.o.b. York, PA, Louviers, CO, or Mountain Pass, CA, effective June 1, 1991. (See table 6.)

Rhône-Poulenc quoted rare-earth prices, per kilogram, net 30 days, f.o.b. New Brunswick, NJ, or duty paid at point of entry, effective at yearend 1991. (See table 7.)

No published prices for scandium oxide in kilogram quantities were available. Yearend 1991 nominal prices for scandium oxide, per kilogram, compiled by the U.S. Bureau of Mines

from information from several suppliers and processors, were as follows: 99% purity, \$2,000; 99.9% purity, \$3,500; 99.99% purity, \$6,000; and 99.999% purity, \$10,000 to \$14,000. Scandium metal prices, as listed by the Johnson Matthey Aesar Group, were as follows: 99.99% purity, lump, sublimed dendritic, \$312.00 per gram; 99.9% purity, 250-micron powder, \$559.00 per 2 grams; and 99.9% purity, lump, vacuum remelted, \$405.00 per 2 grams. Historically, prices for kilogram quantities of scandium metal in ingot form have been about twice the cost of the oxide, while higher purity distilled scandium metal was approximately five times the cost.²⁰

Foreign Trade

Rare-earth imports increased in 1991 from those of the previous year. Imports of ore and compounds are shown in tables 8 and 9. As in the previous 2 years, France dominated the import market. The principal sources of U.S. imports are displayed in figure 6. (See tables 8 and 9 and figure 6.)

Domestic exports of rare earths are shown in table 10. Based on the available export data, Canada, Japan, and Brazil were the leading destinations of rare earths from the United States in 1991. This was a shift from 1990 data when Brazil, Canada, and Japan were the leaders. Principal destinations of U.S. exports are displayed in figure 7. (See table 10 and figure 7.)

World Review

Industry Structure.—Bastnasite, the world's principal source of rare earths, was mined as a primary product in the United States and as a byproduct of iron ore mining in China. Significant quantities of rare earths also were recovered from monazite, a byproduct of heavy-mineral sands mined for titanium and zirconium minerals or tin minerals in Australia, Brazil, China, the C.I.S., India, Indonesia, Malaysia, the Republic of South Africa, Sri Lanka, Thailand,

Taiwan, and the United States. Smaller amounts of rare earths, especially yttrium, were obtained from the mineral xenotime. Xenotime was recovered primarily as a byproduct during processing for tin minerals in Malaysia, Thailand, and Indonesia, but was also produced as a byproduct of processing titanium and zirconium minerals in Australia and China. Rare earths, including yttrium, were also produced from rare-earth-bearing clay in China. The C.I.S. also produced rare earths from the minerals loparite and synchisite-(Y), and from uraniferous phosphorites.

Scandium was recovered as a byproduct of processing ore for tungsten, tin, iron, and beryllium in China, and was previously produced as a byproduct of uranium processing in the United States. (See tables 11 and 12.)

Reserves.—World reserves of rare earths were estimated by the U.S. Bureau of Mines at 83 million tons of contained REO. World reserves were revised upward for 1991 as a result of additional data on the C.I.S. Rare-earth reserves for the Commonwealth of Independent States, which were previously estimated, were reported at 21.4 million tons.²¹ The effect of the large adjustment in world reserves was that China's share of world reserves dropped to 50%.

Australia.—Carr Boyd Minerals Ltd., a subsidiary of Ashton Mining Ltd., continued feasibility and pilot plant studies at its Mount Weld rare-earth-bearing carbonatite. The company also completed an extensive environmental plan, and approval for permitting was expected. Located 35 kilometers south of Laverton, Western Australia, the carbonatite's principal ore minerals are secondary monazite (thorium-deficient) and cheralite. Other rare-earth ore minerals in the deposit are rhabdophane, monazite, cerianite, florencite, and churchite. Mount Weld, one of the richest grade rare-earth deposits in the world, lists reserves at 15.4 million tons grading 11.2% REO,

which includes 1.3 million tons grading 23.6% REO.²² A decision on the project is expected by the end of 1992.

RGC cut back production of separated mineral sand products in 1991 in response to decreased demand. Commissioning of a new mine, the Eneabba West, is expected to occur in 1992 to replace the Eneabba North deposit, which was closed in 1991. RGC noted that 140 hectares at Eneabba and 20 hectares at Capel, were rehabilitated during the year, bringing the total land rehabilitated to 985 hectares. RGC also operated a wetlands habitat center at Capel, which showed a dramatic increase in waterbird population during the year.²³

OUTLOOK

In 1992, domestic demand is expected to remain flat, except for a few growing applications consisting of neodymium-iron-boron permanent magnets, ultraviolet-blocking glass additives, and medical diagnostic agents for magnetic resonance imaging (MRI) enhancement. International demand is also expected to remain level except for a select group of rare-earth-containing products, including permanent magnets, rechargeable batteries, and automotive catalytic converters. International markets are forecast to remain very competitive for the next several years. Rare-earth supplies from the C.I.S. are expected to increase on world markets and be increasingly competitive over the next few years. If developed, Australia's Mount Weld deposit promises to be the most significant new source of rare earths of the decade. New sources and supplies of rare earths have expanded at a faster-than-expected rate during the 1980's and 1990's, a trend that is forecast to continue. The long-term outlook, therefore, is for increasingly competitive markets for the lanthanides, yttrium, and scandium.

²¹Mariano, A. N. Economic Geology of Rare Earth Elements. Ch. 11 in *Geochemistry and Mineralogy of Rare Earth Elements*. Mineralogical Soc. of America, *Review in Mineralogy*, v. 21, pp. 309-337.

²Roberts, W., T. Campbell, and G. Rapp, Jr. *Encyclopedia of Minerals*. Van Nostrand Reinhold, NY, 2d ed., 1990, 979 pp.

³Work cited in footnote 1.

⁴Drew, L., M. Qungrun, and S. Weijun. *The Geology of the Bayan Obo Iron-Rare Earth Niobium Deposits, Inner Mongolia, China*. Unpublished manuscript provided by L. Drew, U.S. Geol. Surv., Reston, VA, 1990, 6 pp.

⁵Graeser, S., and H. Schwander. Gasparite-(Ce) and Monazite-(Nd): Two New Minerals to the Monazite Group for the Alps. *Schweiz. Mineral. Petrogr. Mitt.*, v. 67, pp. 103-113.

Maksimovic, Z., and G. Panto. *American Mineralogist*, v. 68, 1982, p. 849.

⁶Work cited in footnote 2.

⁷Hedrick, J. B., and D. A. Templeton. *Rare-Earth Minerals and Metals—1989*. *BuMines Minerals Yearbook*, May 1991, pp. 14-15.

⁸Work cited in footnote 1.

⁹Work cited in footnote 4.

¹⁰Duncan, R. K. *Geology and Mineralization of the Mt. Weld Rare Earths Deposit, Laverton, Western Australia*. 10 pp. Available upon request from R. K. Duncan & Associates Pty. Ltd., 3 Rosslyn St., Leaderviller, Western Australia, 6007, Australia.

¹¹Ernst and Young's Oil and Gas Federal Income Taxation. Depletion. Ch. 1, James L. Houghton, ed., 1990 ed., pp. 1-2.

¹²Internal Revenue Service—Publication 535. *Business Expenses 1990 Returns*. Depletion. Ch. 11. pp. 30-31.

¹³Haley, T. J. Ch. 40 in *Handbook on the Physics and Chemistry of Rare Earths*, v. 4: Non-metallic Compounds II. North-Holland Publ. Co., 1979, pp. 553-585.

¹⁴Unocal Corporation. 1990 Annual Report. P. 69.

¹⁵Personal Communication with representative from Molycorp., Inc., Mar. 1992.

¹⁶Free-on-board.

¹⁷*Metal Bulletin (London)*. Non-ferrous Ores in Europe. No. 7644, Dec. 30, 1991, p. 24.

¹⁸Values have been converted from Australian dollars (A\$) to U.S. dollars (US\$) at the exchange rate if A\$1.2945=US\$1.00 based on yearend 1990 foreign exchange rates reported in the *Wall Street Journal*.

¹⁹Values have been converted from Australian dollars (A\$) to U.S. dollars (US\$) at the exchange rate of A\$1.3158=US\$1.00 based on yearend 1991 foreign exchange rates reported in the *Wall Street Journal*.

²⁰Hedrick, J. B. *Rare-Earth Metals*. Ch. in *Nonferrous Metal Prices in the United States Through 1988*. *BuMines*, 1990, pp. 81-98.

²¹Kosynkin, V. D., S. Moiseev, Z. C. Peterson, and B. Nikipeleyu. *The C.I.S. Rare Earths Industry Today*. *Concord Trading Company Metals Monthly Report*, v. 2, No. 7, July 1992, pp. 3-7.

²²Work cited in footnote 11.

²³Renison Goldfields Consolidated Ltd. *Annual Report 1991*, p. 55.

OTHER SOURCES OF INFORMATION

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Bureau of Mines Information Circulars.

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Bureau of Mines Minerals Yearbook.

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Bureau of Mines Mineral Facts and Problems.

Other Sources

Metals Week.

Rare-Earth Information Center News.

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(United Kingdom).

Various company annual reports.

TABLE 1
SALIENT U.S. RARE-EARTH STATISTICS

(Metric tons of rare-earth oxides (REO) unless otherwise specified)

	1987	1988	1989	1990	1991
Production of rare-earth concentrates	¹ 16,710	¹ 11,533	¹ 20,787	¹ 22,713	² 16,465
Exports: ³					
Cerium compounds	NA	NA	1,433	1,730	1,369
Rare-earth metals, scandium, and yttrium	NA	NA	425	² 241	71
Ores and concentrates	3,041	4,415	NA	NA	⁴ 459
Rare-earth compounds, organic or inorganic	NA	NA	NA	1,460	1,255
Ferrocerium and pyrophoric alloys	72	⁸ 89	³ 31	⁸ 83	83
Imports for consumption: ²					
Monazite	617	1,058	426	440	—
Metals, alloys, oxides, compounds	724	912	6,125	4,489	6,114
Stocks, producers and processors, yearend	W	W	W	W	W
Consumption, apparent ⁶	11,100	16,800	27,770	² 28,700	22,100
Prices, yearend, dollars per kilogram:					
Bastnasite concentrate, REO basis	2.54	2.54	2.76	2.87	2.87
Monazite concentrate, REO basis	.90	1.15	1.19	1.19	.93
Mischmetal, metal basis	12.35	12.35	12.35	11.02	11.02
Employment, mine and mill ⁵	301	320	381	397	411
Net import reliance ⁶ as a percent of apparent consumption	(⁷)	29	23	² 20	25

¹Estimated. ²Revised. NA Not available. W Withheld to avoid disclosing company proprietary data.

³Comprises only the rare earths derived from bastnasite, as reported in Unocal Corp. annual reports.

⁴Comprises only the rare earths derived from bastnasite as obtained from Molycorp, Inc., company representative.

⁵Because of the implementation of the Harmonized Tariff System in Jan. 1989, import and export categories for 1989-1991 are not necessarily comparable with those of previous years.

⁶Data from The Journal of Commerce Trade Information Service.

⁷Employment at a rare-earth mine in California and at a mineral sands operation in Florida. The latter mines produced monazite concentrate as a byproduct of mining ilmenite, rutile, and zircon, and employees were not assigned to specific commodities.

⁸Imports minus exports plus adjustments for Government and industry stock changes.

⁹Net exporter.

TABLE 2
RARE-EARTH CONTENTS OF MAJOR AND POTENTIAL SOURCE MINERALS

(Percent of total rare-earth oxide)

Rare earth	Bastnasite Mountain Pass, California, United States ¹	Bastnasite Baiyunebo, Nei Monggol, China ²	Monazite Capel, Western Australia ³	Monazite North Stradbroke Island, Queensland, Australia ⁴	Monazite Green Cove Springs, Florida, United States ⁵	Monazite Nangang, Guangdong, China ⁶
Lanthanum	33.2000	23.0000	23.8938	21.5000	17.5000	23.0000
Cerium	49.1000	50.0000	46.0177	45.8000	43.7000	42.7000
Praseodymium	4.3400	6.2000	5.0442	5.3000	5.0000	4.1000
Neodymium	12.0000	18.5000	17.3805	18.6000	17.5000	17.0000
Samarium	.7890	.8000	2.5310	3.1000	4.9000	3.0000
Europium	.1180	.2000	.0531	.8000	.1600	.1000
Gadolinium	.1660	.7000	1.4867	1.8000	6.6000	2.0000
Terbium	.0159	.1000	.0354	.2900	.2600	.7000
Dysprosium	.0312	.1000	.6903	.6400	.9000	.8000
Holmium	.0051	trace	.0531	.1200	.1100	.1200
Erbium	.0035	trace	.2124	.1800	trace	.3000
Thulium	.0009	trace	.0177	.0300	trace	trace
Ytterbium	.0006	trace	.1239	.1100	.2100	2.4000
Lutetium	.0001	trace	.0354	.0100	trace	.1400
Yttrium	.0913	.5000	2.4071	2.5000	3.2000	2.4000
Total	99.8615	100.1000	99.9823	100.7800	100.0400	98.7600

	Monazite East coast, Brazil ⁷	Monazite Mount Weld, Australia ⁸	Xenotime Lahat, Perak, Malaysia ¹	Xenotime southeast, Guangdong, China ⁹	RE minerals in clay Xunwu, Jiangxi Province ¹⁰	RE minerals in clay Longnan, Jiangxi Province ¹⁰
Lanthanum	24.0000	26.0000	1.2400	1.2000	43.3700	1.8200
Cerium	47.0000	51.0000	3.1300	3.0000	2.3800	.3700
Praseodymium	4.5000	4.0000	.4930	.6000	9.0200	.7400
Neodymium	18.5000	15.0000	1.5900	3.5000	31.6500	3.0000
Samarium	3.0000	1.8000	1.1400	2.2000	3.9000	2.8200
Europium	.0550	.4000	.0120	.2000	.5000	.1200
Gadolinium	1.0000	1.0000	3.4700	5.0000	3.0000	6.8500
Terbium	.1000	.1000	.9060	1.2000	trace	1.2900
Dysprosium	.3500	.2000	8.3200	9.1000	trace	6.6700
Holmium	.0350	.1000	1.9800	2.6000	trace	1.6400
Erbium	.0700	.2000	6.4300	5.6000	trace	4.8500
Thulium	.0050	trace	1.1200	1.3000	trace	.7000
Ytterbium	.0200	.1000	6.7700	6.0000	.2600	2.4600
Lutetium	not determined	trace	.9880	1.8000	.1000	.3600
Yttrium	1.4000	trace	61.0000	59.3000	8.0000	65.0000
Total	100.0350	99.9000	98.5890	102.6000	102.1800	98.6900

¹Johnson, G. W., and T. E. Sianeros. Analysis of Rare-Earth Elements in Ore Concentrate Samples Using Direct Current Plasma Spectrometry. Proceedings of the 15th Rare-Earth Research Conference, Rolla, MO, June 15-18, 1981. The Rare Earths in Modern Science and Technology, Plenum Press, NY, v. 3, 1982, pp. 525-529.

²Zang, Z., et al. Rare-Earth Industry in China. Hydrometallurgy, v. 9, No. 2, 1982, pp. 205-210.

³Westralian Sands Ltd. Company Brochure. Product Specifications.

⁴Analysis from Consolidated Rutile Ltd.

⁵Analysis from R G C Minerals (USA), Green Cove Springs, FL.

⁶Xi, Zhang. The Present Status of Nd-Fe-B Magnets in China. Paper presented at The Impact of Neodymium-Iron-Boron Materials on Permanent Magnet Users and Producers Conf. Gorham International Inc., Clearwater, FL, Mar. 2-4, 1986, 5 pp.

⁷Krumholz, P. Brazilian Practice for Monazite Treatment. Symposium on Rare Metals. preprint. pp. 78-82.

⁸Kingsnorth, D. Mount Weld—A New Source of Light Rare Earths. Pres. at the TMS and AusIMM Rare Earth Symp., Mar. 1-5, 1992, San Diego, CA, 8 pp.

⁹Nakamura, Shigeo. China and Rare Metals-Rare Earth. Ch. in Industrial Rare Metals, No. 94, May 1988, pp. 23-28.

¹⁰Introduction to Jiangxi Rare-Earths and Applied Products. Jiangxi Province Brochure at the International Fair for Rare Earths, Beijing, China, Sept. 1985, 42 pp. (In English and Chinese).

TABLE 3
YEAREND RARE-EARTH CONCENTRATE PRICES

(Dollars per kilogram of rare-earth oxide contained)

Year	Bastnasite concentrate, 60% REO ¹		Monazite concentrate, 55% REO plus thoria	
	Actual dollars	1991 constant dollars ²	Actual dollars	1991 constant dollars ²
1972	0.77	2.32	0.35	1.06
1973	.77	2.18	.40	1.13
1974	.84	2.19	.42	1.09
1975	1.10	2.62	.41	.98
1976	1.21	2.71	.36	.81
1977	1.59	3.33	.35	.73
1978	1.72	3.34	.58	1.13
1979	2.09	3.37	.76	1.36
1980	2.09	3.41	.81	1.32
1981	2.25	3.34	.83	1.23
1982	2.43	3.39	.75	1.05
1983	2.43	3.26	.71	.95
1984	2.43	3.12	.64	.82
1985	2.54	3.15	1.09	1.35
1986	2.54	3.07	1.06	1.28
1987	2.54	2.97	.90	1.05
1988	2.54	2.86	1.15	1.30
1989	2.76	2.98	1.19	1.28
1990	2.87	2.97	1.19	1.23
1991	2.87	2.87	.93	.93

¹Pricing for standard package quantities.

²From final 1991 implicit price deflators for gross domestic product* by the Council of Economic Advisors, and not gross national product,* based on 1987=100.

TABLE 4
TARIFF RATES

Item	HTS No.	Most favored nation (MFN)		Non-MFN	
		Jan. 1, 1991	Jan. 1, 1992	Jan. 1, 1991	Jan. 1, 1992
Mineral substances not elsewhere included. Rare-earth metal ores; e.g., xenotime (complex phosphate) and gadolinite, ytterbite, and cerite (complex silicates)	2530.90.0050	Free	Free	Free	Free.
Thorium ores and concentrates. Rare-earth metal ores; e.g., monazite (phosphates of thorium and rare-earth metals)	2612.20.0000	Free	Free	Free	Free.
Rare-earth metals, including scandium and yttrium, whether, intermixed or interalloyed	2805.30.0000	\$0.705 per kilogram	\$0.705 per kilogram	\$4.41 per kilogram	\$4.41 per kilogram.
Cerium compounds, including oxides, hydroxides, nitrate, sulfate, chloride, oxalate, etc.	2846.10.0000	7.2% ad valorem	7.2% ad valorem	35% ad valorem	35% ad valorem.
Mixtures of rare-earth oxides except cerium oxide ¹	2846.90.2010	Free	Free	25% ad valorem	25% ad valorem.
Mixtures of rare-earth chlorides, except cerium chloride	2846.90.2050	Free	Free	25% ad valorem	25% ad valorem.
Rare-earth compounds, including individual rare-earth oxides, rare-earth hydroxide, rare-earth nitrate, and other compounds (excludes cerium compounds, mixtures of rare-earth oxides and mixtures of rare-earth chlorides) ¹	2846.90.5000	3.7% ad valorem	3.7% ad valorem	25% ad valorem	25% ad valorem.
Promethium, salts and other compounds, organic and inorganic	2844.40.0020	Free	Free	Free	Free.
Ferrocerium and other pyrophoric alloys	3606.90.3000	\$0.485 per kilogram + 2.6% ad valorem	\$0.485 per kilogram + 2.6% ad valorem	\$4.41 per kilogram + 25% ad valorem	\$4.41 per kilogram + 25% ad valorem.
Yttrium-bearing materials and compounds, containing by weight more than 19%, but less than 85% yttrium oxide equivalent	9902.26.2200	Free ²	Free ²	25% ad valorem	25% ad valorem.

¹Duty on certain yttrium bearing materials temporarily suspended. See HTS No. 9902.26.2200.

²Duty temporarily suspended effective on or before Dec. 31, 1992.

**TABLE 5
MOLYCORP RARE-EARTH OXIDE PRICES**

Product (oxide)	Percent ¹ purity	Quantity (pounds)	Price per pound
Cerium	99.00	200.00	\$8.75
Dysprosium	96.00	50.00	60.00
Erbium	98.00	50.00	65.00
Europium	99.99	25.00	745.00
Gadolinium	99.99	55.00	65.00
Lanthanum	99.99	300.00	8.75
Neodymium	96.00	300.00	6.75
Do.	99.90	50.00	40.00
Praseodymium	96.00	300.00	16.80
Samarium	96.00	55.00	55.00
Terbium	99.90	44.10	375.00
Yttrium	99.99	50.00	52.50

¹Purity expressed as percent of total REO.

**TABLE 6
MOLYCORP RARE-EARTH COMPOUND PRICES**

Product (compound)	Percent ¹ purity	Quantity (pounds)	Price ² per pound
Cerium carbonate	99.0	150	\$5.10
Cerium fluoride	Tech. grade	250	3.00
Cerium nitrate	96.0	250	2.35
Lanthanide chloride	46.0	525	1.25
Lanthanum carbonate	99.9	175	5.90
Lanthanum-lanthanide carbonate	60.0	200	2.45
Lanthanum-lanthanide chloride	46.0	525	1.05
Lanthanum-lanthanide nitrate	39.0	250	1.75
Neodymium carbonate	96.0	300	4.50

¹Purity expressed in terms of REO equivalent.

²Priced on a contained REO basis.

TABLE 7
RHÔNE-POULENC RARE-EARTH OXIDE PRICES

Product (oxide)	Percent purity	Quantity (kilograms)	Price per kilogram
Cerium	99.50	20	\$20.85
Dysprosium	95.00	20	100.00
Erbium	96.00	20	175.00
Europium	99.99	10	1,400.00
Gadolinium	99.99	50	118.00
Holmium	99.90	5	485.00
Lanthanum	99.99	25	45.00
Lutetium	99.99	2	5,500.00
Neodymium	95.00	20	17.90
Praseodymium	96.00	20	32.00
Samarium	96.00	25	100.00
Terbium	99.90	5	620.00
Thulium	99.90	5	3,300.00
Ytterbium	99.00	10	220.00
Yttrium	99.99	50	90.00

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF MONAZITE, BY COUNTRY

Country	1987		1988		1989		1990		1991 ¹	
	Quantity (metric tons)	Value (thousands)								
Australia			382	\$237	180	\$117				
India	—	—	—	—	—	—	—	—	—	—
Indonesia	—	—	1,144	687	594	413	800	\$686	—	—
Malaysia	527	\$298	197	125	—	—	—	—	—	—
Thailand	594	329	201	105	—	—	—	—	—	—
Total	1,121	627	1,924	1,154	774	530	800	686	—	—
REO content ^a	617	XX	1,058	XX	426	XX	440	XX	—	XX

^aEstimated. XX Not applicable.

¹No data reported by the Bureau of Census for 1991.

Source: Bureau of the Census. REO content estimated by the U.S. Bureau of Mines.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY

Country	1989		1990		1991	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Cerium compounds, including oxides, hydroxides, nitrate, sulfate chloride, oxalate: (2846.10.0000)						
Austria	591	\$4,606	500	\$3,663	1,400	\$20,291
China	—	—	67,100	95,565	6,000	50,529
France	221,019	964,289	287,925	1,818,998	379,104	3,135,018
Germany, Federal Republic of	3,669	154,565	578	47,585	79,951	47,498
Italy	173	42,413	—	—	—	—
Japan	25,353	770,381	2,585	65,683	77,465	1,647,700
Norway	1	4,000	—	—	—	—
U.S.S.R.	—	—	2	2,394	2	2,532
United Kingdom	—	—	540	6,608	1,040	9,355
Total¹	250,806	1,940,254	359,230	2,040,496	544,962	4,912,923
Rare-earth compounds, including oxides, hydroxide, nitrate, and other compounds except chlorides: (2846.90.5000)						
Canada	3,638	504,186	7,106	952,667	11,287	1,369,709
China	90,485	2,336,173	23,064	796,937	154,843	2,477,305
France	6,827,238	18,806,732	4,757,461	25,382,258	3,337,395	19,036,155
Germany, Federal Republic of	252,066	2,141,690	52,252	474,042	839	99,207
Hong Kong	—	—	1,750	31,137	5,115	166,067
Hungary	2,519	9,260	6,224	24,738	10,099	47,699
Japan	132,180	1,949,341	62,829	2,263,418	132,902	6,922,345
Korea, Republic of	—	—	10	4,300	—	—
Netherlands	4,000	4,720	—	—	98	26,506
Norway	11,619	1,089,092	13,905	1,352,905	9,514	901,297
South Africa, Republic of	106	1,067,415	134	1,043,390	—	—
Switzerland	985	19,396	5	2,159	—	—
Taiwan	—	—	200	9,130	—	—
U.S.S.R.	24,864	2,157,938	58,480	4,396,963	9,500	1,659,821
United Kingdom	40,905	598,972	6,226	590,897	1,715	721,596
Other	94	24,333	—	—	19,856	650,864
Total¹	7,390,699	30,709,248	4,989,646	37,324,941	3,693,163	34,078,571
Mixtures of rare-earth oxide except cerium oxide: (2846.90.2010)						
Austria	—	—	50	1,736	1,566	175,641
Brazil	15,061	23,645	—	—	—	—
China	2,108	156,719	68,194	1,267,819	277,943	2,597,046
France	168,978	3,638,954	31,249	3,326,187	44,734	4,452,935
Germany, Federal Republic of	1,050	232,266	2,804	606,921	6,506	1,011,363
Hong Kong	200	12,084	378	17,922	80,384	868,111
India	290,800	460,000	—	—	399,928	240,522
Ivory Coast	—	—	1,000	36,021	—	—
Japan	11,358	1,051,525	26,717	1,132,707	21,968	2,364,992
Norway	1,313	125,261	1,332	173,069	242	42,758

See footnotes at end of table.

TABLE 9—Continued
U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY

Country	1989		1990		1991	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Mixtures of rare-earth oxide except cerium oxide—Continued: (2846.90.2010)						
Taiwan	78	\$5,339	4,150	\$72,201	19,205	\$196,464
U.S.S.R.	4,019	381,893	1,956	362,539	8,536	247,233
United Kingdom	6,933	898,581	12,898	1,020,471	31,265	941,229
Total ¹	501,898	6,986,267	150,728	8,017,593	892,277	13,138,294
Rare-earth metals, whether intermixed or alloyed: (2805.30.0000)						
Austria	4,031	43,785	20,119	205,012	1,400	32,000
Belgium	—	—	—	—	4,950	19,800
Brazil	139,896	728,099	52,669	320,682	30,866	208,963
Canada	7,191	228,706	—	—	—	—
China	110,860	754,063	107,919	562,349	131,480	1,480,056
France	—	—	100	4,520	—	—
Germany, Federal Republic of	1,906	28,619	—	—	34,500	181,579
Hong Kong	—	—	—	—	741	33,727
Japan	7,338	259,851	3,440	153,259	6,767	232,527
Norway	222	19,450	150	28,602	50	8,205
Sweden	980	182,139	981	181,924	—	—
U.S.S.R.	150	23,250	2,258	312,653	2,400	57,086
United Kingdom	21,632	1,908,627	11,170	1,278,221	12,666	1,075,301
Other	30	4,232	34	3,102	—	—
Total ¹	294,236	4,180,821	198,840	3,050,324	225,820	3,329,244
Mixtures of rare-earth chlorides, except cerium chloride: (2846.90.2050)						
Austria	—	—	40	5,500	4,246	117,165
Brazil	837,746	1,250,378	710,988	1,193,349	—	—
China	35,590	297,734	42,620	1,249,338	104,300	1,467,839
France	—	—	784	2,976	—	—
Germany, Federal Republic of	38	3,998	—	—	1	4,000
India	302,000	575,000	211,160	219,725	2,971,130	2,336,576
Ivory Coast	—	—	500	345,273	—	—
Japan	221,379	5,409,189	318,189	9,179,220	65,581	4,453,877
Malaysia	—	—	53,260	170,926	203,874	220,838
Netherlands	—	—	13,500	173,624	—	—
Norway	1,686	181,197	1	1,640	—	—
Taiwan	—	—	11,656	169,621	3,000	37,262
United Kingdom	3,990	364,140	197	31,473	25,110	252,121
Other	19	4,319	56	70,297	—	—
Total ¹	1,402,448	8,085,955	1,362,951	12,812,962	3,377,242	8,889,678
Ferrocerium and other pyrophoric alloys: (3606.90.3000)						
Austria	4,083	103,494	27,201	496,180	20,414	406,476
Belgium	—	—	4,126	54,974	3,400	64,023
Brazil	37,031	482,609	20,469	251,636	20,596	260,672
Canada	—	—	—	—	1,250	2,417

See footnotes at end of table.

TABLE 9—Continued
U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY

Country	1989		1990		1991	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Ferrocerium and other pyrophoric alloys—Continued: (3606.90.3000)						
France	42,541	\$633,583	33,071	\$565,458	44,340	\$628,533
Germany, Federal Republic of	—	—	5,768	87,960	159	6,460
Hong Kong	—	—	—	—	500	5,099
Japan	—	—	495	12,780	2,250	46,905
United Kingdom	—	—	2,000	26,000	—	—
Other	—	—	—	—	88	3,486
Total¹	83,655	1,219,686	93,130	1,494,988	92,997	1,424,071

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 10
U.S. EXPORTS OF RARE-EARTHS, BY COUNTRY

Country	1990		1991	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Cerium compounds: (2846.10.0000)				
Argentina	240	\$2,726	2,400	\$20,869
Australia	46,932	428,488	21,009	89,837
Belgium	4,858	21,400	2,523	16,960
Brazil	319,991	558,347	228,459	724,330
Canada	308,585	1,833,895	292,633	2,022,321
Chile	580	3,107	—	—
China	4,369	19,447	2,400	19,656
Colombia	—	—	882	4,200
Egypt	2,880	16,427	3,433	26,240
France	65,507	466,086	35,904	212,097
Germany, Federal Republic of	156,278	1,709,933	108,502	1,001,295
Greece	6,131	2,900	1,794	2,621
Hong Kong	95,750	663,777	106,868	655,274
India	1,920	11,040	—	—
Indonesia	5,038	24,093	700	54,710
Israel	2,541	21,635	3,347	21,159
Italy	35,577	109,016	12,000	74,277
Japan	266,312	1,635,416	231,140	1,037,752
Korea, Republic of	230,823	1,377,622	61,051	963,527
Luxembourg	2,400	18,672	—	—
Malaysia	654	2,978	—	—
Mexico	18,937	133,939	30,628	74,835
Netherlands	3,511	25,729	794	7,052
New Zealand	620	6,977	—	—
Portugal	6,720	29,491	5,760	27,603
Saudi Arabia	1,920	10,982	960	4,944
Singapore	300	3,341	39,520	159,591
Spain	26,460	167,322	25,440	145,467
Taiwan	56,096	297,401	118,741	518,094
Thailand	18,720	137,971	13,552	102,551
Trinidad and Tobago	4,314	55,000	3,672	51,437
Turkey	2,853	13,306	—	—
United Kingdom	26,356	132,665	5,976	38,766
Venezuela	4,760	33,579	7,897	52,849
Other	838	8,677	550	64,234
Total	1,729,771	9,983,385	1,368,535	8,194,548
Rare-earth compounds: (2846.90.0000)				
Australia	18,739	339,495	650	7,650
Belgium	94,810	259,362	43,893	166,487
Brazil	819	171,125	19,059	129,782
Canada	98,285	1,282,567	39,973	825,404
Chile	668	11,214	—	—

See footnotes at end of table.

TABLE 10—Continued
U.S. EXPORTS OF RARE-EARTHS, BY COUNTRY

Country	1990		1991	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Rare-earth compounds—				
Continued (2846.90.0000)				
Colombia	2,717	\$28,253	—	—
France	1,041,588	2,854,058	418,723	\$576,858
Germany, Federal Republic of	61,171	4,032,682	93,284	2,424,107
Italy	2,568	122,752	276	58,412
Jamaica	46,748	41,931	—	—
Japan	640,791	6,275,777	927,538	12,299,034
Korea, Republic of	5,838	481,971	63,766	1,764,122
Mexico	30,531	151,433	77,536	139,340
Netherlands	6,941	558,228	29,517	786,771
Romania	3,403	95,160	—	—
Singapore	80	150,035	124	200,708
Spain	1,933	53,363	2,318	33,200
Taiwan	10,866	275,240	8,588	458,967
United Kingdom	12,276	407,250	14,623	170,877
Venezuela	802	38,130	1,089	9,401
Other	3,640	379,547	52,135	903,347
Total	2,085,214	18,009,573	1,793,092	20,954,467
Rare-earth metals, including				
scandium and yttrium:				
(2805.30.0000)				
Australia	1,415	11,682	—	—
Bahamas	—	—	18,954.00	18,745
Canada	2,335	199,874	10,215	194,712
China	108	4,500	—	—
Dominican Republic	81,455	15,000	—	—
France	1,016	66,726	833	160,392
Germany, Federal Republic of	937	9,420	27	8,340
Guatemala	19,958	10,583	—	—
Guyana	45,910	45,000	—	—
India	327	50,739	5	5,000
Japan	12,601	188,439	25,337	1,874,990
Korea, Republic of	3,364	74,573	—	—
Lichtenstein	255	96,900	—	—
Malaysia	797	11,666	—	—
Mexico	977	22,183	—	—
Netherlands	12,854	100,422	150	7,350
Netherlands Antilles	362	4,500	—	—
Norway	106	15,200	—	—
Singapore	592	16,047	—	—
St. Lucia	14,490	18,100	—	—
Switzerland	394	166,802	—	—
Taiwan	722	63,200	—	—
United Kingdom	27	20,174	1,966	288,068
Venezuela	—	—	1,000	6,650
Other	120	37,728	548	118,612
Total	201,122	249,458	59,035	2,682,859

See footnotes at end of table.

TABLE 10—Continued
U.S. EXPORTS OF RARE-EARTHS, BY COUNTRY

Country	1990		1991	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Ferrocerium and other pyrophoric alloys: (3606.90.0000)				
Argentina	16,984	\$41,059	13,553	\$31,855
Australia	87,229	190,471	124,567	262,556
Barbados	54,275	63,606	55,737	64,048
Belgium	83,106	1,087,949	204	5,832
Brazil	14,803	21,740	2,200	14,071
Canada	44,200	2,348,565	37,261	1,987,397
Costa Rica	32,194	68,355	7,483	66,690
Cyprus	18,943	23,850	14,834	16,863
Denmark	17,433	111,079	5,377	84,920
Ecuador	—	—	42,400	138,512
El Salvador	75,747	51,795	12,955	15,300
France	80,881	254,954	18,555	343,857
Germany, Federal Republic of	132,190	542,323	243,520	1,533,980
Greece	55,682	124,753	47,717	120,052
Haiti	23,526	49,258	—	—
Honduras	24,321	54,059	—	—
Hong Kong	341,118	583,490	319,632	521,546
Indonesia	12,512	55,338	3,838	24,050
Jamaica	84,645	88,204	50,407	75,019
Japan	67,061	680,986	50,392	646,589
Jordan	13,934	16,217	29,046	16,012
Kuwait	21,666	35,011	—	—
Mexico	46,609	113,483	22,437	146,497
Netherlands	48,706	122,114	137,208	213,570
Nicaragua	12,296	14,522	—	—
Saudi Arabia	27,712	68,366	81,868	215,764
Singapore	127,739	238,335	214,026	294,713
Sweden	54,640	15,391	148	3,000
Switzerland	19,476	95,751	14,354	20,094
Thailand	12,795	22,511	468	14,097
Taiwan	68,124	150,455	18,920	919,670
United Arab Emirates	135,282	162,080	131,392	184,428
United Kingdom	61,982	320,406	166,491	195,298
Other	115,406	868,822	246,179	1,166,519
Total	2,033,217	8,685,298	2,099,616	9,342,799

Source: Bureau of the Census.

TABLE 11
MONAZITE CONCENTRATE: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons, gross weight)

Country ²	1987	1988	1989	1990	1991 ³
Australia	12,813	11,872	¹ 13,000	¹ 11,000	5,000
Brazil	4,332	2,817	1,900	² 2,000	2,000
India ³	4,000	4,000	4,300	³ 3,500	5,000
Malaysia	2,908	2,920	2,948	³ 3,323	1,900
South Africa, Republic of ³	1,200	1,200	1,200	³ 1,317	1,300
Sri Lanka ³	200	200	200	200	200
Thailand	458	590	631	³ 377	400
United States	W	W	W	W	W
Zaire	97	168	175	¹ 124	120
Total	26,008	23,767	² 24,354	² 21,841	15,920

¹Estimated. ²Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

³Table includes data available through Apr. 22, 1992.

⁴In addition to the countries listed, China, Indonesia, North Korea, the Republic of Korea, Nigeria, and the U.S.S.R. may produce monazite, but output, if any, is not reported quantitatively, and available general information is inadequate for formulation of reliable estimates of output levels.

⁵Reported figure.

TABLE 12
RARE EARTHS: WORLD MINE PRODUCTION, BY COUNTRY

(Metric tons of REO equivalent)

Country ¹	1988	1989	1990	1991 ²
Australia ³	⁶ 530	⁷ 150	⁶ 050	3,850
Brazil	1,690	1,900	¹ 1,100	1,100
Canada ³	100	100	—	—
China	29,640	25,220	16,480	² 16,150
India ³	2,200	² 365	¹ 925	2,750
Malaysia	1,630	1,646	¹ 828	1,050
South Africa, Republic of ³	660	660	² 724	715
Sri Lanka ³	110	110	110	110
Thailand	375	365	358	360
U.S.S.R. ³	8,500	8,500	8,500	8,500
United States ³	11,533	20,787	22,713	² 16,465
Zaire	92	96	⁶ 8	65
Total	⁶ 3,060	⁶ 8,899	⁵ 9,856	51,115

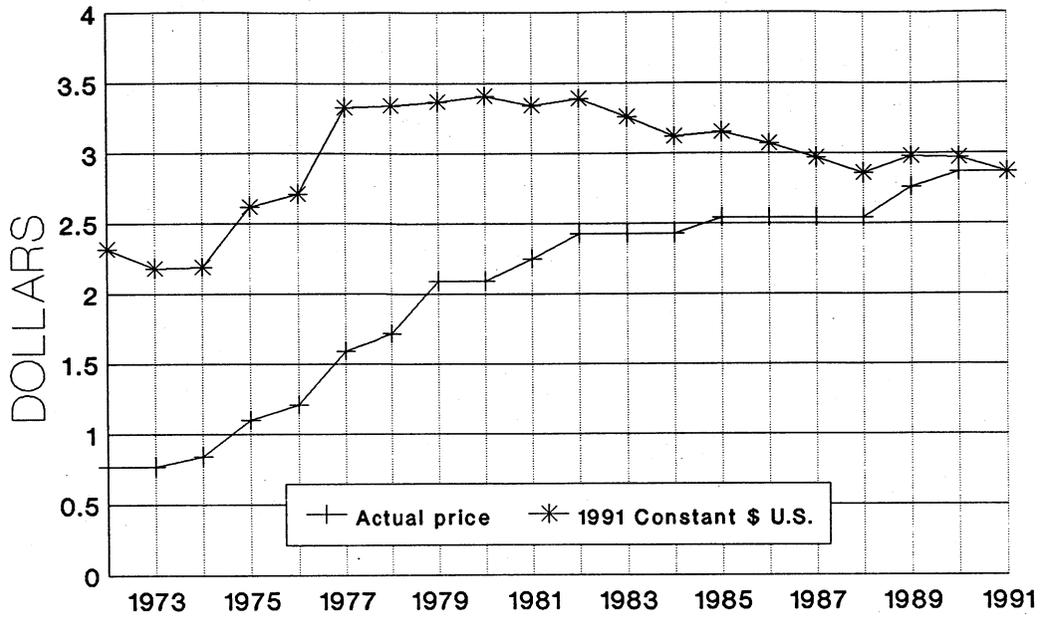
¹Estimated. ²Revised.

³In addition to the countries listed, rare-earth minerals are believed to be produced in Indonesia, North Korea, Mozambique, and Vietnam, but general information is inadequate to formulate reliable estimates.

⁴Reported figure.

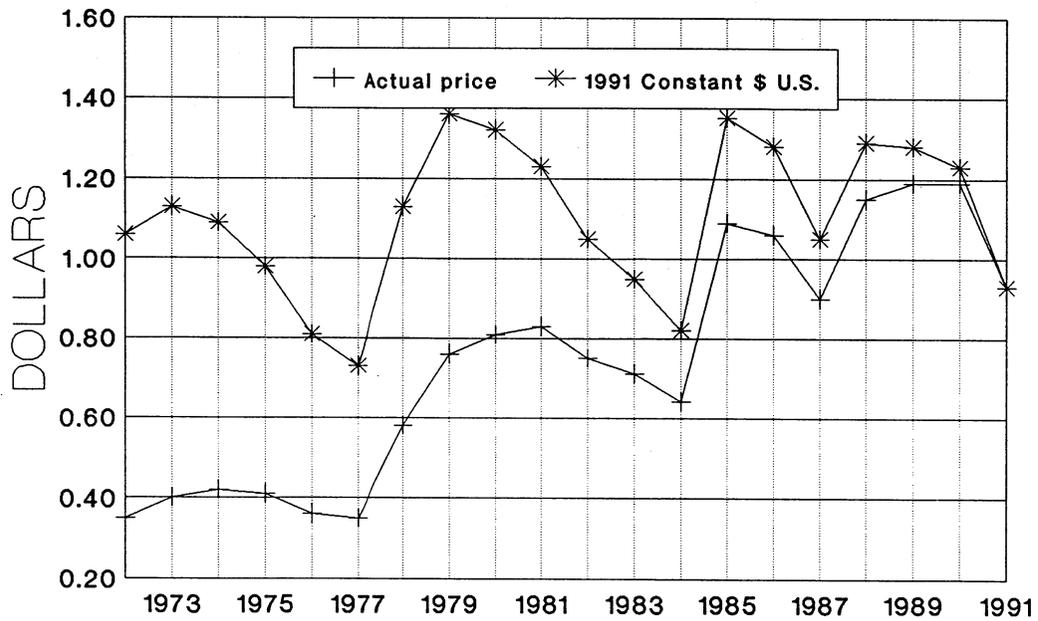
⁵Comprises only the rare earths derived from bastnaesite as reported in Unocal Corp. annual report, 1990 and from company sources.

FIGURE 1
BASTNASITE CONCENTRATE PRICES¹



1/60% REO content.

FIGURE 2
MONAZITE CONCENTRATE PRICES¹



1/55% REO content.

FIGURE 3
U.S. RARE-EARTH MINE AND MILL EMPLOYMENT

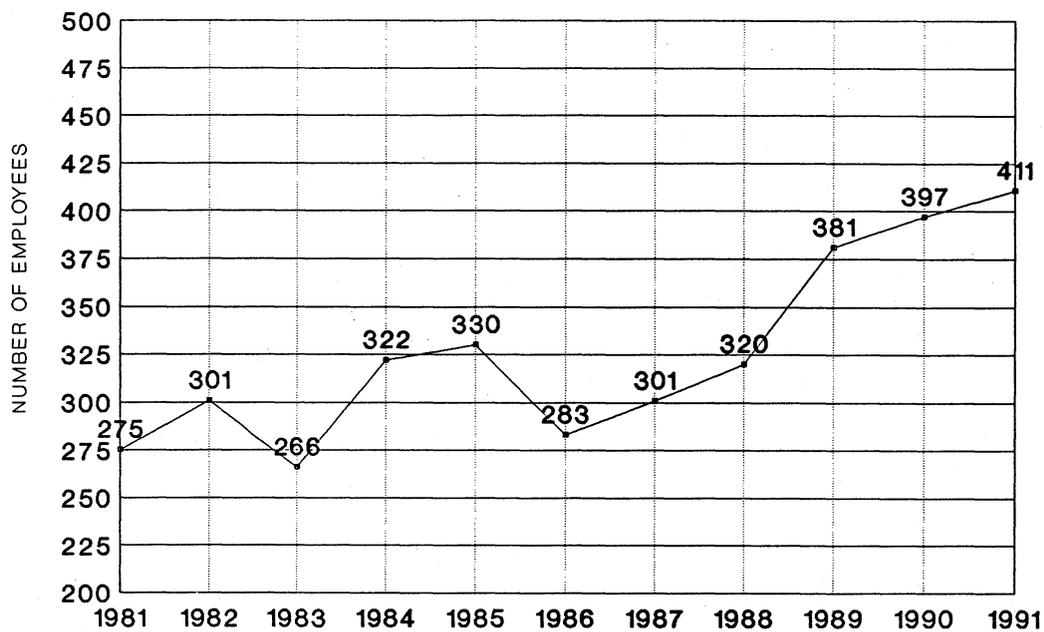


FIGURE 4
U.S. BASTNASITE CAPACITY UTILIZATION

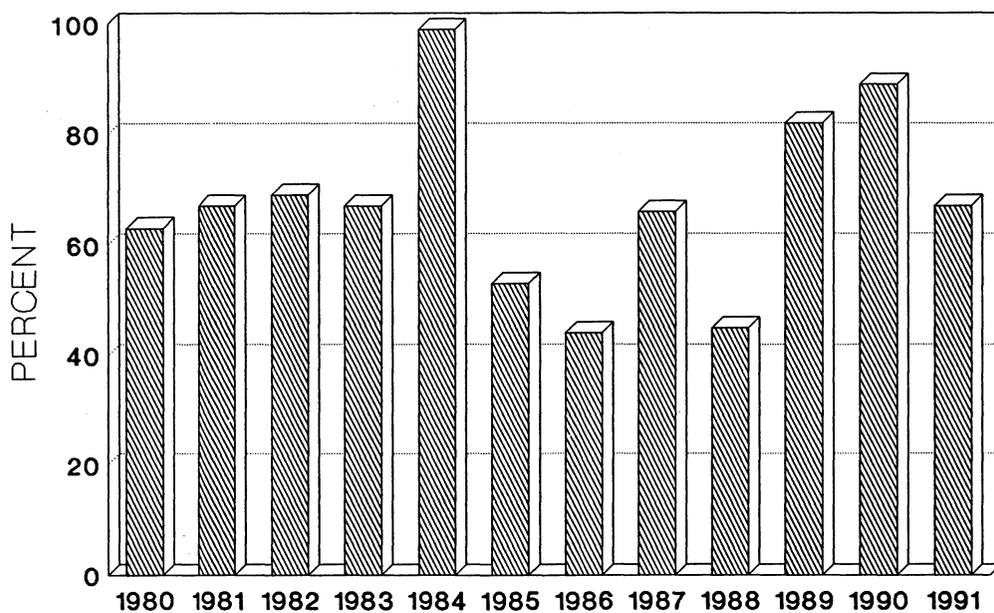


FIGURE 5
U.S. MONAZITE CAPACITY UTILIZATION

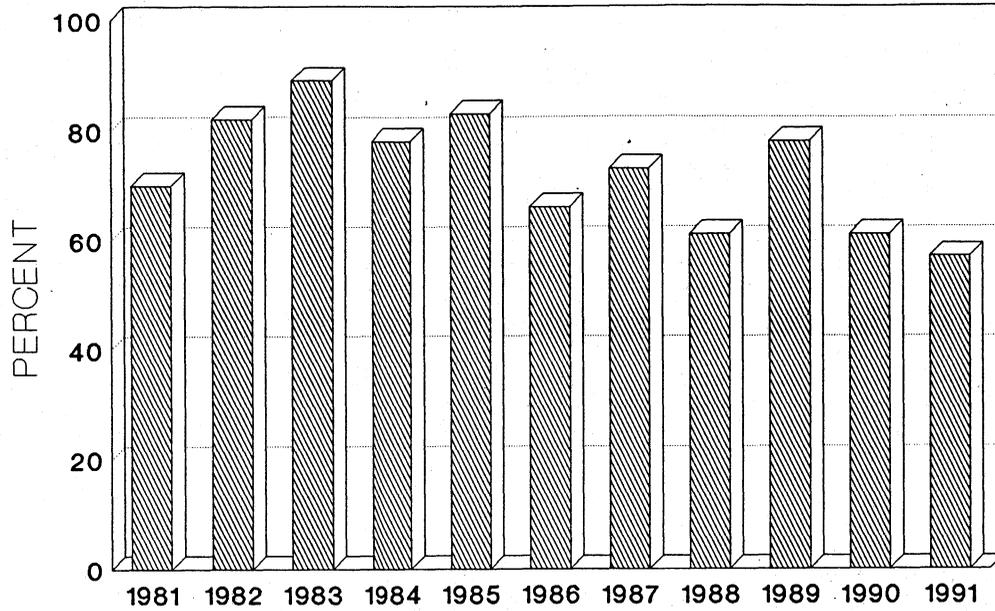
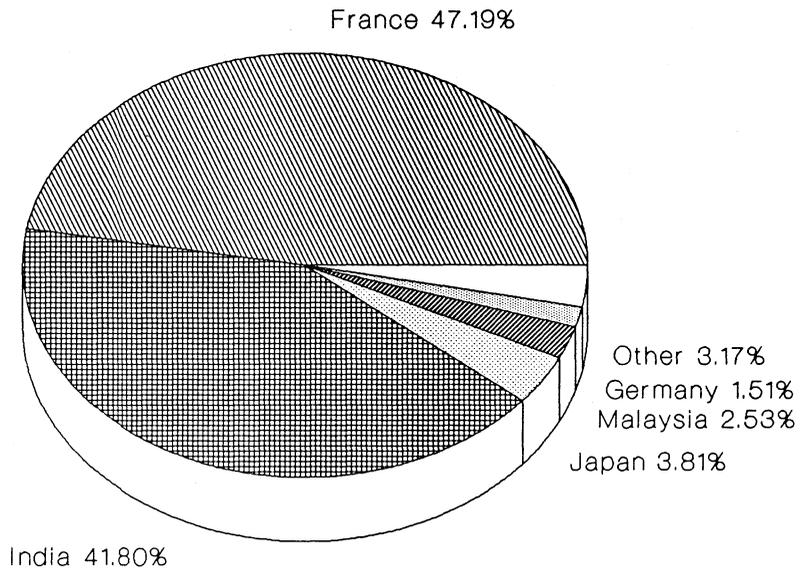
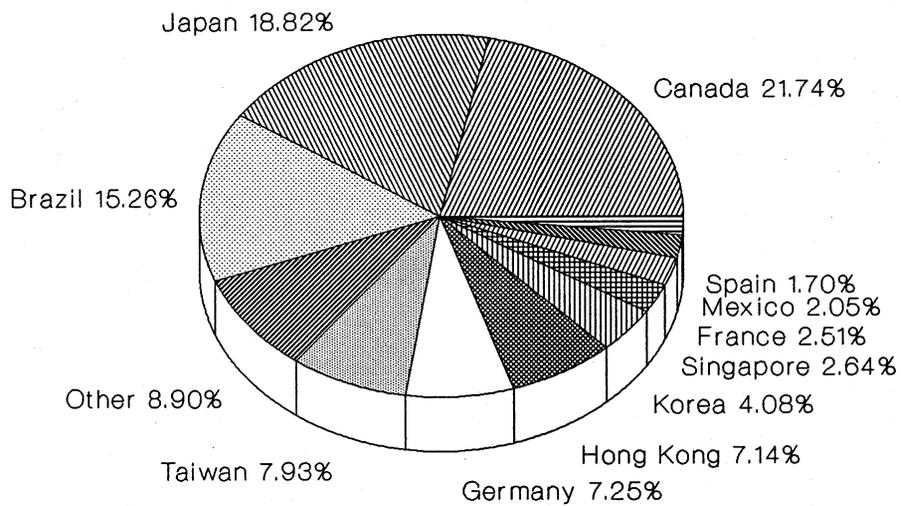


FIGURE 6
U.S. IMPORTS OF RARE-EARTHS (PERCENT REO)



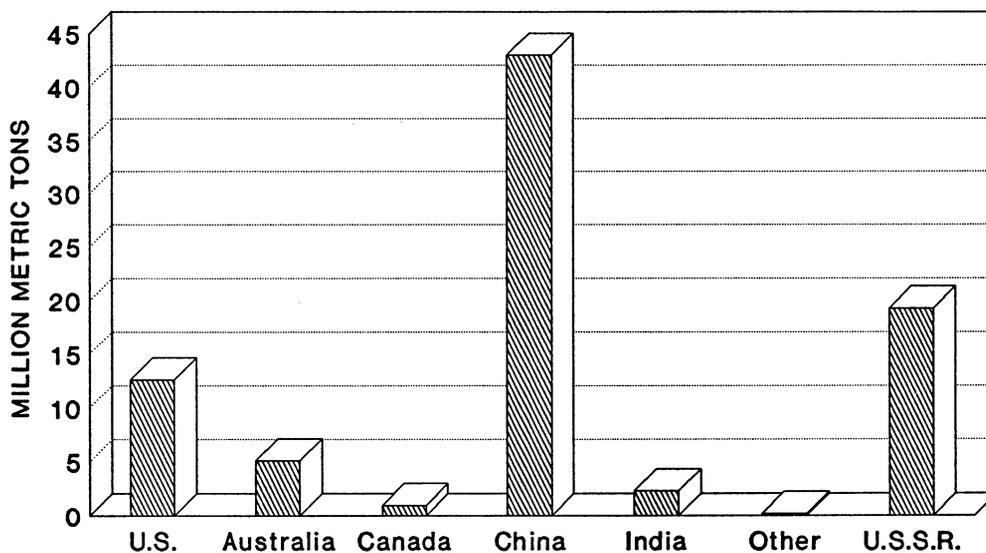
Source: Bureau of the Census.

**FIGURE 7
U.S. EXPORTS OF RARE-EARTHS (PERCENT REO)**



Source: Bureau of the Census.

**FIGURE 8
WORLD RESERVES OF RARE EARTHS (REO CONTENT)**



RECYCLING—NONFERROUS METALS

By Janice L. W. Jolly, John F. Papp, and Patricia A. Plunkert

Mrs. Jolly is a physical scientist (geologist) with more than 30 years in the mining industry, including 16 years with the U.S. Bureau of Mines. Mrs. Jolly is currently the copper specialist for the U.S. Bureau of Mines, a position she has held since 1983. Dr. Papp, a physical scientist with 20 years of U.S. Bureau of Mines experience, has been the commodity specialist for chromium since 1983 and was the coordinator for this report. Ms. Plunkert, a chemist with 23 years of U.S. Bureau of Mines experience, has been the commodity specialist for aluminum since 1987.

INTRODUCTION¹

Recycling, a significant factor in the supply of many of the key metals used in our society, provides environmental benefits in terms of energy savings, reduced volumes of wastes, and reduced emissions associated with the energy savings.

The estimated value of recycled nonferrous metals in 1991 exceeded \$7.5 billion and is an increasingly important component of economic activity in the United States. Table 1 shows salient U.S. recycling statistics for selected metals. Table 2 shows salient U.S. apparent consumption and recycling statistics for those same metals. Figure 1 shows a general flow scheme for recycling. (See tables 1 and 2 and figure 1.)

Legislation dealing with recycling was introduced in Congress during 1991. Although this legislation was not enacted, similar legislative proposals are anticipated. In January 1991, a bill was introduced in the Senate that would have created a Bureau of Recyclable Commodities within the Department of Commerce. Another bill was introduced in the House of Representatives as H.R. 2746, which would have established such a Bureau within the Department of Commerce. The function of this Bureau would be to collect statistics on recyclable materials, including metals and glass, and report on such factors as technology, types, grades, prices, recycling rates, and

capacities, in addition to promoting purchasing of recycled goods. A number of the materials and objectives described in the proposed bill are currently part of the activities of the U.S. Bureau of Mines.

As part of its Commodities and Materials Program, the Bureau provides information and analysis on more than 100 raw and/or processed minerals. Collected data are assessed by commodity specialists, and information is disseminated to government, industry, and academia through consultative services and more than 100 recurring publications. This work examines and reports on minerals and materials trends as well as environmental aspects of the entire life cycle of minerals use.

The Bureau's Research Directorate included studies on recycling of advanced materials and of metallurgical residues and effluents currently discarded, on impurity control during recycling, and on design for reuse or waste minimization. Fiber-reinforced alloys, dispersion strengthened metals, titanium aluminides, and rechargeable battery replacement alloys are examples of advanced materials for which recycling technology was investigated by the Bureau. Metallurgical residues such as steelmaking sludges, fine particle slurries, rare-earth processing residues, and titanium pickle liquors were also investigated to reduce the volumes of these materials and recover contained values. To increase the efficiency of recycling, the Bureau investigated the

control of impurities such as magnesium and zinc in aluminum scrap and the removal of copper from ferrous scrap. The Bureau also investigated methods to remove heavy-metal contaminants from mineral processing and manufacturing wastes and to stabilize those heavy metals not removed. Recent research addressed copper smelter wastes, primary and secondary lead smelter wastes, and steel industry furnace dust.

Because of the increasing importance of recycling to domestic metal supply and the intense public interest, the U.S. Bureau of Mines is initiating this separate chapter on nonferrous metal recycling as part of its Annual Report series. A separate chapter on iron and steel scrap has already been part of this series for many years. The focus of this initial chapter is on aluminum and copper recycling. In subsequent years, contents will be expanded to include all nonferrous recycling information currently included as part of the chapters covering the primary commodities. These will include lead, tin, zinc, and precious metals, among others.

ALUMINUM²

Domestic Data Coverage

Domestic recycling data for aluminum are developed by the U.S. Bureau of Mines from a voluntary survey, "Aluminum Scrap," of U.S. operations. Of the 96 companies and/or plants to

which monthly or annual survey requests were sent, 74 responded, representing 78% of the total scrap consumed shown in table 5.

Background

Definitions, Grades, and Specifications.—New aluminum-base scrap, generated in the production of intermediate and end products of aluminum metal, may be pure (unalloyed), segregated (one alloy type), or mixed (two or more alloys). It includes solids, such as new casting scrap; clippings or cuttings of new sheet, rod, wire, and cable; borings and turnings from the machining of aluminum parts; and residues, drosses, skimmings, spillings, and sweepings.

New scrap is further defined as either "runaround" (home) scrap or purchased scrap. Runaround or home scrap is new scrap that is recycled by the same company that generates it; such scrap by definition never leaves the company generating it and, therefore, is never marketed as scrap. Purchased scrap is new scrap that is purchased, imported, or treated on toll by secondary smelters, the original aluminum product suppliers, or others. New aluminum scrap that is purchased from manufacturers of end products may be referred to as consumer scrap. Purchased new scrap is sometimes referred to as prompt industrial scrap.

Old scrap, all of which is considered as purchased, comes from discarded, used, and wornout products. It includes such products as aluminum pistons or other aluminum engine or body parts from junked cars, aluminum used beverage cans (UBC's) and utensils, and old wire and cable. Sweated pig is scrap that has been sweated or melted into a pig or ingot form for convenience and economy in shipping and storage. Obsolete scrap is new, unused, but technologically obsolete aluminum end products, outdated inventory materials, production overruns, and spare parts for machines and equipment no longer being used. In the United States, both sweated pig and

obsolete scrap are considered old scrap. (See figure 2.)

Industry Structure.—The secondary aluminum industry was born shortly before World War I at a time when the United States had only one primary aluminum producer. There was little need for a secondary industry prior to that time because the supply of aluminum scrap was limited. Although the secondary industry did grow during World War I and after, that growth was modest until World War II. World War II created many changes in the domestic aluminum industry. The primary industry had changed from a monopoly to a triopoly, while the secondary industry had progressed from a remelter to a smelter. Secondary smelters thus emerged from the war years with the technology needed to process huge quantities of aircraft scrap and other partially manufactured aluminum products. It was at this point in history that the secondary aluminum industry started its phenomenal growth.

Aluminum recovery from scrap has become an important component of the supply-demand relationship in the United States. Between 1950 and 1974, aluminum recovered from old scrap (post consumer scrap) accounted for approximately 5% of the total domestic demand for aluminum. Increased costs for energy and growing concerns over waste management have provided the impetus for increased recycling rates. (See figure 3.)

Aluminum recovered from scrap has shown a tenfold increase since 1950. (See figure 4.) The recovery of aluminum from old scrap has shown an even more rapid expansion over the same period of time. In addition to improvements in recycling technologies, some of the increase in aluminum scrap recovery can be attributed to a changing and growing end-use consumption pattern. Aluminum products, developed for the construction, transportation, and electrical industries, tend to have a fairly long life and are slow to enter the scrap supply stream. The emergence of the aluminum beverage can in the mid-1970's with a life cycle of less than 1 year added

dramatically to the potential aluminum scrap supply. (See figure 5.)

Aluminum scrap, in one form or the other, is recovered by almost every segment of the domestic aluminum industry. Primary producers (integrated aluminum companies), independent secondary aluminum smelters, independent fabricators, foundries, and chemical producers can recover aluminum from scrap. Primary producers and independent secondary smelters are the major consumers of aluminum scrap.

The independent secondary aluminum smelter is the core of the commercial secondary aluminum industry. Unlike scrap dealers, who buy and sell many different metals, and diecasters, who cast other metals, the secondary aluminum smelter is totally dependent on one metal—aluminum. The sole purpose of the secondary smelter is to transform aluminum scrap into a marketable product. Scrap is purchased by smelters wherever it can be purchased economically. Purchasing habits can also depend on how badly a smelter needs scrap. During periods of excess scrap supply, smelters tend to be very selective in their scrap purchases. When the supply of aluminum scrap becomes short, however, it is frequently necessary to buy scrap that would not ordinarily get recovered.

Independent secondary aluminum smelters, by definition, consume scrap and produce alloys for the diecasting industry. A cursory look at the distribution of these secondary smelters in the United States consequently reveals a heavy concentration of smelters in the automotive and appliance manufacturing areas of the country.

The other major consumers of aluminum scrap are the primary aluminum producers (integrated aluminum companies). The types of scrap processed by the primary producers tend to be more segregated than those processed by the secondary smelters. Primary producers participate in either the collection or utilization of new aluminum scrap. They frequently purchase scrap from their industrial customers or on a contract conversion

basis. Major primary aluminum producers also operate can recycling programs. These producers have set up thousands of collection centers around the country for UBC's. The large-scale aluminum beverage can reclamation programs of these aluminum producers have added substantially to the rate of aluminum recovery from old scrap. The UBC component of old scrap consumption has doubled since 1975. (See figures 6 and 7.)

Aluminum scrap is also traded in the international marketplace. Price and shipping costs are usually the determining factor in choosing whether to sell scrap in the domestic or international markets. U.S. trade in aluminum scrap has grown dramatically over the past 30 years. Most of the scrap shipped into the United States comes from Canada. However, since the mid-1970's, the major recipient of U.S. scrap exports has been Japan.

The secondary aluminum industry has developed into a major market force in the domestic aluminum industry. The recycling of scrap provides a source of aluminum that not only helps the aluminum industry to maintain its growth but also helps to conserve energy and to slow the depletion of bauxite resources.

Technology.—In recycling, aluminum-base scrap is usually melted in gas- or oil-fired reverberatory furnaces of 30,000- to 100,000-pound capacity. The furnaces have one or two charging wells separated from the main bath by a refractory wall that permits only molten metal into the main bath. The principal refining of aluminum-base scrap is the removal of magnesium by treating the molten metal with chlorine or with various fluxes such as aluminum chloride, aluminum fluoride, or mixtures of sodium and potassium chlorides and fluorides. To facilitate handling, a significant proportion of the old aluminum scrap, and in some cases new scrap, is simply melted to form a solid ingot called "sweated pig," which must be treated further to produce specification-grade ingot.

Aluminum drosses containing about 30% metallics are usually crushed and

screened to bring the metallic content up to about 60% to 70%. They are then melted in a reverberatory furnace, with the molten aluminum metal collecting on the bottom of the furnace. Salt slags containing less than 30% metallics may be leached with water to separate the metallics.

Annual Review

In 1991, an estimated 2.5 million metric tons of metal was recovered from purchased aluminum scrap. Of this total, approximately 60% was recovered from old scrap. The recovery of metal from old scrap satisfied almost 30% of the total domestic aluminum metal demand for the year. The predominant type of purchased scrap processed was UBC scrap, accounting for more than one-half of the old scrap consumed. (See tables 3, 4, 5, and 6.)

Production.—According to a survey conducted by the Aluminum Association Inc., the Institute of Scrap Recycling Industries (ISRI), and the Can Manufacturers Institute, a record 56.85 billion aluminum UBC's were recycled in the United States in 1991. This was the 20th consecutive year that the number of recycled aluminum beverage cans increased. An industry representative attributed the increase to a growing consumer recycling ethic, an increased number of communities that collect recyclables at curbside, and greater involvement and investment in can recycling by brewers, soft drink fillers, airlines, charities, and the military. Despite the increase in the number of cans recycled, the recycling rate for 1991, 62.4%, was down slightly from the 1990 rate, 63.6%. The president of the Aluminum Association cited the continuing increase in can usage and the possibility that some recyclers held cans collected during 1991 in the hope that their value might be higher in 1992 as possible reasons for this slight downturn.

Aluminum Co. of America (Alcoa) and Reynolds Metals Co. launched major promotional efforts to increase the recycling of formed aluminum containers

and household aluminum foil food wrap. In May, Alcoa announced a new program to increase the recycling of formed aluminum containers, including those used for frozen entrees, baking items, and deli trays. Alcoa and participating members of its 2,800 owned and contracted buyback and processing centers around the country began accepting clean, dry, and separated containers. In addition, Alcoa developed two pilot curbside programs designed to test the level of consumer participation.

Reynolds began a program in five market areas to promote the recycling of household aluminum foil food wrap. The cities involved were the Baltimore, MD/Washington, DC, area; Richmond, VA; San Francisco, CA; Seattle, WA; and Tampa, FL. The "Great Balls of Foil" program included television advertisements and school activities where schools competed to collect the largest ball of clean foil. Cash prizes were awarded to the winners, and the schools earned money for various programs by selling the used foil to Reynolds. Reynolds reported that their recycling centers collected almost 153,000 pounds of foil scrap during the year. Schools in Baltimore and Richmond participated in the foil contest and together collected more than 2.5 tons of aluminum foil.

Golden Aluminum Corp. announced that construction had been completed at its new 130-million-pound-per-year canstock plant in San Antonio, TX. The company noted that the rolling mill would use continuous casting technology to manufacture sheet products for the food and beverage can market. The feedstock for this plant would be recycled material, primarily UBC's. The company expected the plant to come on-line by the end of the year and to begin full-scale operations early in 1992.

Roth Brothers Smelting Corp. announced plans to increase capacity at its East Syracuse, NY, secondary aluminum smelter by 25,000 tons per year. The company said the decision was based on projections for increased use of secondary aluminum in the automotive industry.

Two companies announced plans to build plants to process saltcake, a byproduct of aluminum dross processing. Imco Recycling Inc. planned to build a salt recovery plant at its Morgantown, KY, plant, and Solar Aluminum Technology Services planned to build a plant in Wendover, UT. Both plants were expected to recover both aluminum metal and reusable fluxing salts.

Markets and Prices.—Purchase prices for aluminum scrap, as quoted by American Metal Market (AMM), fluctuated during the year, but closed the year at much lower levels than those at the beginning of the year. The yearend price ranges for selected types of aluminum scrap were as follows: mixed low-copper-content aluminum clips, 38 to 39 cents per pound; old sheet and cast aluminum, 33 to 35 cents per pound; and clean dry aluminum turnings, 34 to 36 cents per pound.

Prices for UBC's fluctuated during the year, but closed 10 cents per pound lower than prices at the beginning of the year. Aluminum producers' buying prices for processed and delivered UBC's, which began the year in a range of 42 to 46 cents per pound, reached a high for the year of 49 to 53 cents per pound in March. The price range at the end of the year was 32 to 37 cents per pound.

Secondary aluminum ingot prices, as quoted by AMM, also fluctuated during the year, but generally trended downward and closed much lower than prices at the end of 1990. The yearend 1991 price ranges for selected secondary aluminum ingots were as follows: alloy 380 (1% zinc content), 59.5 to 61 cents per pound; alloy 360 (0.6% copper content) and alloy 413 (0.6% copper content), 62.5 to 63.5 cents per pound; and alloy 319, 61 to 62.5 cents per pound.

The London Metal Exchange (LME) continued its investigation into the potential for an LME secondary aluminum ingot contract. A final decision on the introduction of such a contract was expected by mid-1992.

Foreign Trade.—Exports of aluminum scrap continued to decrease after reaching a 5-year high of more than 575,000 tons in 1989. Japan continued to be the principal destination of aluminum scrap exported, accounting for more than one-half of the total in 1991.

Imports for consumption decreased slightly in 1991 after increasing steadily over the previous 5-year period. Canada remained the major shipping country to the United States, supplying almost three-fourths of the total aluminum scrap imports in 1991. (See tables 7 and 8.)

World Review.—According to preliminary data published by the World Bureau of Metal Statistics in June 1992, world production of secondary aluminum was about 5.6 million tons in 1991. According to their statistics, the United States was the world's largest producer of secondary aluminum, followed by Japan at about 1.5 million tons, and Germany at about the 0.5-million-ton level.

Aluminum Can Recycling Europe (ACRE) published figures showing that 21% or 32,350 tons of used aluminum cans was recycled in Europe in 1991. ACRE, organized in 1987, was funded by the major aluminum can sheet producers, Alcan Aluminium Ltd., Alcoa, Pechiney, Reynolds, and Vereinigte Aluminium-Werke AG (VAW). In countries where ACRE has been active since 1987, recycling rates have grown on average 20% to 25% per year. Some of the reported UBC recycling rates for various countries were as follows: Austria, 25%; Greece, 26%; Italy, 15%; Sweden, 85%; Switzerland, 50%; and the United Kingdom, 11%.

Australia.—The UBC market in Australia was estimated to be about 30,000 tons per year. Almost 63% of all aluminum cans was reported to be recycled, and aluminum UBC's accounted for almost 38% of Australia's total aluminum scrap market. Most of the UBC's were collected through clubs, self-help agencies, and charities using one of the more than 1,100 collection centers scattered throughout the country.

Although most of the UBC's were recycled locally, some were exported, primarily to Japan.

The total Australian scrap aluminum market was estimated by industry leaders at 80,000 to 90,000 tons per year. The non-UBC scrap market was dominated by three companies: Simsmetal Ltd., Nonferral Pty. Ltd., and Affinity Metals Pty. Ltd. Simsmetal had secondary aluminum plants in Melbourne and Adelaide; Nonferral had plants in Sydney and Melbourne; and Affinity had an ingot smelter in Melbourne and a dross recycling plant at nearby Geelong.³

France.—Pechiney announced plans to build two specialized foundries for aluminum beverage can recycling in anticipation of greater quantities of cans being used in the European market in the next few years. The first was in Nogueres, where the company closed a primary aluminum smelter in October of this year. The company expected the plant to be processing 20,000 tons per year of cans by early 1992. The second plant was to be built at Pechiney's strip mill at Neuf Brisach on the French-German border. This foundry was expected to be operational some time in 1992 and to have the same capacity as the plant in Nogueres.

Germany.—Subject to the approval of the German Federal Cartel Office, Klockner and Co. and SMG Metallwerke GmbH announced an agreement to merge their secondary aluminum activities to form a new company, Sekundaraluminiumwerke GmbH (SAW). Sommer Metallwerke would own 80% of the new company, and the remainder would be owned by Klockner. Included in the merger were Sommer Metallwerke's three secondary aluminum plants, which produced about 130,000 tons per year of aluminum, and Klockner's 38,000-ton-per-year secondary aluminum plant.

Japan.—According to the Japan Aluminum Alloy Refiners Association, production of secondary aluminum and alloys in fiscal year 1991 was 1,252,300 tons, a decrease of 1.3% from the

1,268,463 tons recorded in fiscal year 1990. The association had a membership of 39 secondary aluminum producers.

Daiki Metals, a wholly owned subsidiary of Daiki Aluminium, reported the completion of a new scrap processing plant in Kameyama. Since 1985, Daiki Metals had operated a plant in Yuki that used a gravity separation process to treat scrap and to separate various metal values, including aluminum, copper, lead, and zinc. The company reportedly bought the residue left over from the shredding of automobiles, processed it at Yuki, kept the aluminum for its own use, and sold the other metals in the domestic market or exported them to neighboring countries. The new plant at Kameyama was expected to process between 1,000 to 2,000 tons per month of scrap initially. The company hoped to expand the plant to 4,000 tons per month sometime in the future.

Japan announced plans to implement a new program to increase the recycling of aluminum and steel cans. The program set a goal to raise the recycling rate on both aluminum and steel cans to 60% by 1994 from the 1990 rate of 42.6% for aluminum and 44.8% for steel.

Spain.—Production of secondary aluminum in 1991 totaled 96,000 tons, an increase of 11% compared with that of the previous year and reportedly the highest level of production in 10 years. Spain's secondary aluminum industry included about 33 companies employing approximately 500 people. Thirteen of these companies were members of Spain's secondary aluminum producers' association, Aseral, which reportedly accounted for about 86,000 tons of Spain's production in 1991.

United Kingdom.—Alcan announced the opening of a new UBC recycling plant in Warrington. The 50,000-ton-per-year plant reportedly was the first recycling plant in the European Community (EC) dedicated solely to the recycling of aluminum beverage cans.

Cookson Aluminium announced that construction had begun on a new

secondary aluminum smelter at Repton near Derby. Although the new smelter would have a design capacity of 30,000 tons per year, the net increase in capacity for Cookson would be only 5,000 tons per year. The new smelter was to replace the recently mothballed 10,000-ton-per-year smelter at North Cave on Humberside and the existing 15,000-ton-per-year smelter at Repton. The company expected the new smelter to be completed in 1992.

Europe's largest can market was in the United Kingdom, where total sales reportedly expanded from less than 6 billion cans in 1988 to more than 7 billion cans in 1991. During the same period of time, the aluminum contribution to the market reportedly increased steadily from 42% to 60%. The United Kingdom began its national can recycling activities in 1989, and recycling rates for aluminum cans have doubled from a reported rate of 5.5% in 1990 to an 11% recycling rate in 1991.

Current Research.—Production of aluminum extrusions involves the generation of relatively large quantities of process scrap in the form of billet butt ends, extruded section cutoffs, and rejected lengths of extrusions. As a rule, the quantity of scrap generated amounts to about 20% to 25% of the metal used. The quantities of recyclable in-house scrap for extruders usually ranges between 2 and 30 million pounds per year. Some extruders had expressed an interest in remelting their own recyclable scrap in-house. However, conventional billet casting shops reportedly could not be economically built and operated for these small production quantities. A new concept was therefore developed in which a melting and casting furnace was designed so that scrap could be continually charged and molten metal continuously tapped. The molten metal was then cast continuously in a small horizontal continuous casting unit. The cast logs were automatically cut into billets of any desired length by a saw integrated into the casting unit and conveyed to a billet storage table.

Instead of the usual batch operations, continuous production took place.⁴

All molten aluminum processes generate dross: from 1% to 2% for holding furnaces at primary smelters, 3% to 5% for scrap melting furnaces, and even higher for thin gauge materials. Dross can contain up to 70% metallic aluminum. The classical dross-recycling process is the rotary salt furnace process. The patented Alcan dross treatment process uses a water-cooled plasma gas arc heater (plasma torch) installed in a specially designed rotary furnace. A stack from the furnace conducted dust emissions to a bag collector. The new process completely eliminated the salt flux used in the conventional dross treatment process. Alcan reported metal recovery efficiencies of 85% to 95% for this new plasma process.⁵

Most of the major producers of aluminum-lithium (Al-Li) alloys have taken the position that the airframe manufacturers must segregate scrap. The airframers have resisted this, and most of them have insisted that recycling, particularly lithium recovery, should be addressed by the producers. So far, only a few have processed the small quantities of Al-Li scrap available by diluting with large quantities of conventional aluminum scrap and then removing the lithium by chlorine fluxing. This worked for very small volumes or on a trial basis, but was impractical for long-range operations. When larger quantities are available on a continuous basis, it is not known how much producers will or can process with dilution, whether they can handle it with environmental acceptability, whether or not they will be interested, and just how much they will be willing to pay for it. Alcoa reported the development of a process for handling mixed scrap that stripped the lithium into the dross and resulted in a recovered ingot with less than 10 parts per million (0.001%) lithium residual. The company noted that it was also working on a process for lithium recovery from that dross.⁶

Outlook

The driving forces behind the increasing use of resource recovery as an alternative to sanitary landfill are both economic and political. The increasing costs of suitable land for landfills, the stringent regulations on leachate control, and other costs are making resource recovery more attractive. Aluminum scrap has been the highest unit valued commodity recovered from municipal refuse. It has been estimated that metals represent about 9% by weight of municipal solid waste (MSW), but only about 3% in terms of volume. While the aluminum can composes less than 1% by weight of MSW, it frequently represents more than one-half of the revenue collected by municipal recycling programs. The public and industry have recognized the economic and ecological value of recycling aluminum cans. Through aggressive promotion and expanding collection methods, the volume of aluminum cans being recycled into the aluminum supply stream has increased dramatically year by year.

As the public and industry become more sensitive to the issue of waste management, the benefits of recycling will become more evident. The aluminum industry, with its long history of recycling experience and its vast network of collection centers, will be well-positioned to take advantage of this increased interest. The domestic and world secondary aluminum industries should continue to expand. In the short term, the growing acceptance of aluminum beverage cans (with their very short life cycle) in overseas markets could lead to a more rapid growth in the recovery of secondary aluminum in countries outside the United States, where the aluminum beverage can already dominates the market. However, as more and more aluminum is used in products with longer life cycles, such as automobiles, more scrap will enter the market for recovery and increase the secondary production levels in both the domestic and world markets of the future.

COPPER AND COPPER ALLOY SCRAP⁷

Background

Definitions, Grades, and Specifications.—The Institute of Scrap Recycling Industries Inc. (ISRI) recognizes about 53 classes of copper and copper alloy scrap and issues a scrap specifications circular each year that is widely used in the trade.⁸ Although there are several grades of scrap within each, the major unalloyed scrap categories were known generally as No. 1 copper (common names—Barley, Berry, Candy, and Clove), which contained greater than 99% copper and often is simply remelted, and No. 2 copper (common names—Birch, Cliff, and Cobra), which usually must be re-refined. In addition to the many copper and copper alloy scrap types, there are many special types such as lower grade skimmings, ashes, and residues, which contain 12% to 30% copper, and others of lower copper grade such as electronic scrap, refining slags, printed circuit and other clad materials, and metal-laden waste liquors.

Copper scrap is classified into two general categories called old and new scrap. *New scrap*, or manufacturing scrap, is generated during the fabrication of copper products and returned to the mill for reprocessing, or sold, and is not considered a new source of copper supply. *New scrap* is termed "runaround" or *home scrap* when it was generated internally at the plant reusing it, or it may be called *purchased return scrap* when returned by a customer from a plant external to that purchasing and reusing it.

Old scrap is generated from worn out, discarded, or obsolete copper products and thus, is considered to be a new source of supply.

Resources.—Since World War II, the ever-increasing reservoir of copper products in use, much of which was eventually recycled as "old" copper, has provided annually between 19% to 33% of U.S. apparent demand and, on

average, has provided about 18% of world copper demand. The U.S. scrap reservoir of items in use, or abandoned in place, over the same period has increased from about 16.2 million tons in 1940 to about 69.8 million tons, increasing since 1983 at the rate of about 1.2 million tons per year. This scrap "reservoir" does not include a sizable and growing pool of "new" scrap that is recycled every year. As shown in figure 8, new scrap currently comprises about 25% of total U.S. copper consumption; total scrap comprises about 44% of consumption. In 1940, the world copper reservoir of copper materials in use, or abandoned in place, was about 32.9 million tons; by 1991, this potential reservoir of scrap exceeded 189.5 million tons, as shown in figure 9. The U.S. share of the world's copper scrap reservoir has been decreasing, from 49% in 1940 to about 37% in 1991. (See figures 8 and 9.)

The U.S. Bureau of Mines reported⁹ that in 1974 about 70% of all copper products that were on the market, or had become obsolete, was not being recovered. If recovery methods and scrap prices continued as they were at that time (1961-70), the annual increase of unrecovered copper in the U.S. scrap reservoir was expected to be more than 2.2 million tons by the year 2000. Of this amount, about one-half would lie in the consumer and general use areas. Copper that is not recovered may be placed in one of three categories: (1) still in use and unaccountable, (2) solid waste disposal, and (3) dissipated and lost. It was estimated that as much as 30% to 50% of the unrecovered copper products was entering solid waste disposal sites. Copper has few applications that are dissipative by nature; only about 0.5% of total copper consumed may be lost and unretrieved, such as copper used in chemicals. Items still in use, or unaccountable, may be recycled at some future time, but because of copper's long life, this is not immediately necessary or convenient in many cases. The recovery of some items may be delayed because of the economics involved; for example, some buried cables may not be recovered

until such time as market prices permit the cost and time needed to recover them.

The availability of copper scrap is linked with the quantity of products consumed and their life cycles, or duration. Many estimates have been made about individual products, and these product lives may even vary from country to country, according to construction methods and concepts. However, according to one source, copper in electrical plants and machinery averages 30 years; in nonelectrical machinery, 15 years; in housing, 35 years; in transportation, 10 years; and in all other end-use sectors, about 10 years. The average for the industry was roughly estimated to be about 25 years.¹⁰

Using this 25-year average for copper recyclability, one analyst calculated a theoretical scrap availability trend.¹¹ The total amount of available scrap can be obtained by comparing annual consumption of past years with statistics of scrap to be recycled 25 years later; the result gives 75% as the average rate of recovery from 1959 to 1965. This theoretical calculation further predicted that scrap availability would increase by 39% over the period between 1984 and 1990, or about 5% to 6% per year. Because total world copper consumption increased only an average of 2.4% over this time, the percentage contributed by world scrap should always get higher. If this were always the case, scrap might be expected to not only become gradually more abundant, but also more available. However, there are many more considerations in the recovery of copper scrap that limit the economics of its immediate recovery according to this theoretical schedule. For example, some analysts recently have estimated that, because of manufacturing efficiencies developed, the percentage of "new" scrap generated by U.S. manufacturers has fallen to one-half that of 20 years ago. Thus, while manufacturing levels may recover after the 1991 recession, the new scrap level will be lower. In addition, because of the move toward low-lead alloys, consumers will become more reliant on No. 1 copper. The industry predicted that there will be a decline in

the use of leaded auto radiators and other high-lead scrap.¹²

The rate of old scrap recovery is limited not only by copper's long life, but also by its essential uses and by the sensitivity of scrap collection to market prices. On average, the rate of old scrap recovered in the United States, as a percentage of total scrap consumption, declined from 50% to 60% in the 1940's to almost 40% in the 1980's. The decline in the old scrap component was the result of an increasing manufacturing base from which to generate new scrap and of a demand pattern changing to one dominated by electrical uses. Electrical items, which now account for more than 70% of copper consumed, were less likely to be substituted, replaced, and scrapped than items in other end-use sectors. The long service life for utility and building cable, among other reasons, results in a practical limit to the amount and rate at which old scrap from this source can be recovered. Historically, old scrap recovery not only improved during periods of high refined copper prices, but also increased at any time that primary supplies became scarce, including the deep recessionary years of the 1930's. Scrap recovery is very price and cost sensitive. More obsolete scrap surfaces as the value of primary copper increases. Public utilities with obsolete and unused cable, either buried under the earth or lying in sewers, begin to study the cost of recovery when the prices are high enough.

Preparation and Processing Technology.—Because scrap is a bulky material, the customary practice is to bale light scrap and cut heavy scrap to size so that it can be handled. An important copper recycling material is cable scrap. Whereas burning the cable to remove the plastic parts previously was acceptable, this is no longer always possible or desirable. Thus, mechanical dismantling of the cables is common practice through cutting, granulating, and use of various metal separation techniques to separate the plastics and fluff from the metal. The cable is granulated to about 30 millimeters. The plastics are removed

during the granulation stages by air classification. Iron impurities can be removed by magnet and aluminum and copper separated by weight. Cables with lead or tin impurities have to be refined after processing at a secondary smelter.

Most old scrap retrieved from the marketplace must be reprocessed either by smelting and refining, or by leaching and electrowinning to form a pure copper product. Fire refining in a reverberatory or other furnace may be sufficient for the better grades of scrap. The fire-refining process uses oxidation, fluxing, and reduction, and a refined ingot, wirebar, slab, or billet is usually poured. The reduction is accomplished by partly covering the molten metal with coke and inserting green wood poles through the furnace door. Copper oxide in the melt is converted to copper by the reducing gases formed. For higher grades of refined cathode, however, the poorer grades of scrap must be first smelted with various fluxes, poled to remove oxygen, and then poured into anode form for further processing in an electrolytic refinery. Byproducts, such as tin and precious metals, may be retrieved during the preliminary procedures of smelting or during refining from the tankhouse sludges. Other impurities, such as antimony, arsenic, iron, and lead may be removed in the slag by fluxing.

The most complex copper-containing recycling material is electronic scrap. Electronic scrap arises from computers and increasingly from other durables and printed circuit boards. The relatively high gold and silver content makes this scrap economically attractive. On the other hand, electronic scrap not only contains valuable metals, but also plastics, organic flame retardants, and ceramics. Mechanical dismantling by crushing and separation by means of density or conductivity is one way to process this material. Thermal dismantling also can be done, but with some problems in controlling the toxic pyrolysis gases. More recently, some companies have developed leaching, solvent-extraction, and electrowinning procedures for treatment of certain types of electronic and circuit board scrap, as

well as waste fluids that contain copper and other metals. A low-grade copper cathode, copper sulfate, copper oxides, copper precipitates, and byproduct metals can be produced through this method.

Black copper (75% to 80% copper) is the principal product of the blast furnace and still contains some iron and zinc along with most of the lead, nickel, and tin of the charge. Traditionally, this material is refined in a scrap converter, which is of a more modest size than its primary cousin; also, coke is added liberally to the charge, adding extra heat and providing a mildly reducing condition, thus facilitating removal of lead, tin, and zinc in the gas stream. A copper anode is poured for final refining in an electrolytic tankhouse.

The flue dust of the smelter or converter process contains mainly lead, tin, and zinc, most of which is recovered when the dusts are processed. A Pierce Smith converter or a Top Blow Rotary Converter (TBRC) can be used for the converting process of alloy scrap. The TBRC consists of a cylindrical vessel that rotates on its midaxis. Processing of complex copper-containing materials, such as drosses, flue dust, catalysts and collector dust, slimes from electroplating wastewater, and metal-rich slags from converter processes, also requires versatile production processes. Reverberatory or electric rotary melting furnaces are used for casting various copper forms, such as slabs, cakes, or billets. Asarco shaft furnaces may be used with holding furnaces in conjunction with continuous casting systems.

Metallurgical wastes, such as mine waters, effluents, and sludge from hydrometallurgical and electrochemical plants may contain many valuable metals along with toxic chemicals. These wastes, if discharged directly into the sewage system, cause pollution. Most plants have built-in water recirculation systems where practical, attempting to reuse and recapture some of the metal content. Many of these wastes must be treated for metal recovery. In general, a combination of various hydrometallurgical techniques such as precipitation, cementation, ion exchange, solvent

extraction, reverse osmosis, gaseous reduction, and electrolysis are used. Cementation has been successfully employed to recover copper from waste effluents. Solvent extraction and ion exchange are highly selective methods for treatment of solutions to separate copper from other common metals.

There have been various analyses of energy costs of refining, but an Italian study reached the conclusion that the cost of producing secondary copper was about one-half the cost of producing primary copper. In fact, excluding the energy content of materials used, which can be estimated at about 5 gigajoules (Gj) per ton, refined copper from ore would require about 70 Gj of total energy, while to recover pure copper from scrap would require only about 35 to 40 Gj per ton.¹³ Another source indicated 28.2 million kilocalories per ton for producing primary copper from ores and only 4.5 million kilocalories per ton for secondary copper.¹⁴

Industry Structure.—The scrap consuming industries of the United States include secondary smelters and refiners, ingotmakers, brass and wire rod mills, foundries, and miscellaneous manufacturers and chemical plants. Fabricators such as the brass and wire rod mills prefer to use clean scrap as much as possible to conserve on using more expensive primary refined metals. Certain technical limitations can limit how much scrap can be used, but it is generally possible to use 100% scrap if it is available in proper form and composition. Factors affecting the maximum amount of scrap used include the greater manual effort needed to charge to furnace; longer melting times for scrap if it is fine or loose, resulting in fewer pounds produced per furnace and worker-hour; and lastly, the availability of suitable scrap. Parts of the copper industry are very scrap intensive. Certain industries, such as the brass rod industry (80% to 90% scrap) use higher amounts of scrap than others by tradition. Others, such as brass sheet and strip (10% to 75% scrap), use less.

In both Europe and the United States, many smelters and refiners use scrap as feed, a trend that has been increasing along with the need for purer forms of copper. In addition to secondary smelters, the concentrate smelters also are strong competitors for some classes of scrap, prompted by the lower unit cost. In recent years, about 40% of refined copper produced in Western Europe and about 22% of refined copper in the United States were derived from copper scrap. Copper scrap accounts for about 19% of the world's refined copper production. A manufacturer may generate up to 60% of scrap as clippings, trimmings, stampings, borings, and turnings when processing copper and copper-base products into finished articles. This "new" scrap is readily used by brass and copper tube mills to generate new semifabricated forms with very little treatment. Because minimal cleanup procedures are needed, this type of scrap is commonly called "direct melt" scrap. In the United States, direct melt scrap provided about 66% of the total scrap supply in 1991, or about 807,000 tons.

Most wire rod mills use very little scrap as direct feed without further processing. Advances in continuous-cast rod technology require some mills to use very clean, high-grade scrap, if used directly at all. Scrap comprises less than 5% of feed used. Brass mills are principal consumers of No. 1 copper scrap and account for more than 75% of the copper alloy scrap intake. Scrap purchases by brass mills are based primarily on activity levels at the mills and the relative price between cathode and No. 1 scrap, rather than upon overall copper prices. When business conditions are strong, brass mills have access to large volumes of return scrap. Scrap imports also help. When both manufacturing and imports decline, mills may increase their cathode purchases.

Almost all of the copper raw material used to make specialty alloy ingot for use in foundries was scrap, much of it used in a direct melting process. In the United States, four secondary smelters and refineries are associated with copper tube

mills or wire rod mills. Three companies fire refine for direct use or sale to the market or smelt low-grade copper scrap to produce anode, blister, or black copper for further refining by another company. There are about 28 ingotmakers, 1 of the largest of which is associated with a foundry, and about 700 foundries. All of these companies consume scrap as their basic raw material.

Large quantities of slags are produced in copper smelting plants. Depending on the ore or scrap quantity being processed, up to 4 tons of reverberatory slags will be generated in the production of 1 ton of copper. Limited space in many plants has encouraged research activities into finding uses for slag. This resulted in the development of a number of uses, such as railroad ballast, aggregate for roadmaking, soil conditioners, slag wool, in foamed form as porous aggregate for lightweight concrete, and in granulated form for cementmaking and so forth. In recent years, demand for home insulating materials, due to the increasing cost of energy, has prompted researchers to promote making mineral wool from copper reverberatory slags. The aforementioned products are only manufactured when the metal content of the slag is very low. Whether a slag is discarded is a matter of economics as well as of environmental considerations. Metal recovery from the slag is worth considering if it contains more than 1% of primary nonferrous metal.¹⁵

Annual Review

Legislation and Government

Programs.—Under consideration in the United States in 1991 were stricter regulations for emissions, higher costs for waste disposal, legislation limiting the lead content of alloys and in drinking water, and the Basel Convention. Legislation limiting the content of lead in copper alloys was being considered. The industry claimed that improperly applying waste-handling laws to scrap could have a stifling effect on recycling.

On June 7, 1991, the EPA published the final rule for the National Primary

Drinking Water Regulations and Maximum Contaminant Level Goals for Lead and Copper in Drinking Water (56 FR 264460). Under the rule, water delivery systems would be required to optimize corrosion control treatment if one of the following action levels was exceeded at consumers' taps: an average lead level greater than 0.010 milligrams per liter (mg/l); a copper level in 5% of the samples exceeding 1.3 mg/l; or a pH of less than 8.0 in 5% of the samples. In addition, water delivery systems would be required to implement public education, as specified, if the level of lead exceeded 0.02 mg/l in 5% of the tap samples. The final rule would apply the lead and copper action levels as a trigger for corrosion control treatment only to systems serving less than 50,000 persons. Larger water systems would have to install treatment to minimize lead and copper levels at consumer taps. Based on source water and tapwater monitoring, a State may determine that source water treatment is necessary to minimize lead and/or copper levels.

The secondary processing industry claimed that a major portion of the scrap export market could be curtailed if the Solid Waste Disposal Act (SWDA)(H.R. 3736) was implemented. If scrap metals are found to be hazardous waste under Section 201 of the SWDA, then the export controls of SWDA would govern their entry into international trade. In addition to adverse scrap export effects, at proposed 0.1% heavy-metal concentration, the legislation defined many discarded consumer goods as hazardous even though these same goods currently were being recycled safely with no harmful release of hazardous constituents, according to the industry. Metallic products that would come under the hazardous definition included such commonly used items as stainless steel flatware and foil wine wrappers. For many, if not most, metals recyclers, becoming classified as hazardous waste facilities would be economically disastrous. The legislation defined as hazardous many millions of tons of metals recycled each year, based on the presence of certain heavy metals, with no

evidence for low level toxicity of these metals. This legislation would deem as hazardous waste any discarded material that contained more than 0.1% of any heavy metal, such as beryllium, cadmium, chromium, lead, mercury, and nickel. This proposal grew out of concern that wastes bearing heavy metals could release those metals to the environment. Thus, stainless steel, with far more than 0.1% nickel and chromium, would be deemed hazardous, regardless of whether the heavy metals could escape into the environment. Copper, brass, bronze, galvanized steel, and other metals that are commonly and safely recycled also would not pass this test.

Issues.—The cost for dumping hazardous materials, such as lead-containing plastic wire coverings and fluff, is high. While acceptable in some other nations, such as in Japan, incineration to destroy some of the unwanted plastics in the United States does not appear to be an acceptable solution for much of the covered wire. Cable scrap is an important source of metal, and whereas the plastic parts of the cable were removed previously by burning, stringent legislation on emissions has restricted this procedure. Thus, mechanical dismantling of cables has become common. An estimated 340,000 tons of cable is chopped every year in the United States, resulting in about 158,000 tons of plastic waste that must be disposed of in some way. Thermoplastic resins are recyclable, but some high lead-containing plastics are not. Lead is used as a stabilizer in plastic cable coverings. Although choppers do not present the air pollution problems that incinerators do, there are landfill problems with plastic byproducts. For some types of wire, such as the so-called grease wire, which tends to gum up choppers, wire-burning is preferable and continues to be done. The wire scrap processing industry continued to investigate all areas of plastics use.

A new joint venture between U.S. and Canadian interests was formed to process thousands of tons of vinyl fluff generated by a wire chopping operation. B.F.

Goodrich, I. Waxman & Sons, and Plastic Recovery Systems Inc. were planning to have a pilot plant built and operational by early 1992.¹⁶ Plastic Recovery Systems developed reclamation technology to separate complex wire and cable fluff, and B.F. Goodrich developed the process to further refine the scrap polyvinyl chloride into new products. Waxman planned to build the 15-million-pound-per-year upscale pilot plant. First to make a commercial product as a result of the technology was Utility Plastics, a subsidiary of Brooklyn Union Gas, which was making traffic cones for the U.S. Department of Transportation.

In late 1990, the EPA issued a strategy for reducing lead exposure based on a goal of reducing lead exposures to the fullest extent through market-based incentives to limit or eliminate lead use; using regulatory mechanisms, such as the Toxic Substances Control Act (TSCA), to reduce the use of lead in current and future products; and identifying and encouraging cleaner technologies for mining, smelting, and processing lead. Studies were to be made on potential hazardous exposures that might occur in the future after disposal of any lead-bearing product, including copper alloys. The EPA would explore the desirability and feasibility of discouraging overall consumption of lead in any form.

The Lead Exposure Reduction Act (S. 2637 and H.R. 5372) and Lead Ban Act of 1990 (S. 2593) were viewed by the scrap industry as having the potential to impede copper alloy recycling in the United States. Restrictions would have been placed on solder (greater than 0.1% lead), copper alloy plumbing fixtures (greater than 2% lead), and many other items, such as soldered copper pipe, many lead-containing plastics wire coatings, and brass and copper plumbing fittings and construction materials, as well as the scrap materials derived from them. The Brass and Bronze Ingotmakers testified that these bills, which sought to restrict all lead-containing products, could actually result in more lead being released into the environment if such laws were passed. Currently, much of the lead-bearing

copper alloy material is safely recycled, but the legislation could result in at least 6 to 10 million tons per year going to landfills, where lead could leach into the ground waters. The industry asked for rewording of the legislation to state clearly that it does not apply to the processing or distribution of copper alloy products of the recycling process. A new organization, Recyclers of Copper Alloy Products (RE-CAP), was formed to make the industry's views known. Among the members were the following: the Brass and Bronze Ingot Manufacturers, Inc.; the Copper Development Association; the Copper and Brass Fabricators Council (CBFC); the ISRI; the American Foundrymen's Society; the American Cast Metals Association; the Non-Ferrous Founders' Society; the Plumbing Manufacturers Institute; the Air-conditioning and Refrigeration Institute; and the American Pipefittings Association.

Leaded copper alloys were presenting numerous problems to foundries in the United States, from disposal of wastes and industrial hygiene, to increasingly stringent requirements on the lead content of plumbing fittings. Alternatives to leaded copper alloys were being developed; however, any of these alternatives would require a source of lead-free copper scrap for ingot producers. Currently, much of the copper scrap available to ingot producers contains lead. Without a viable process to remove lead from the recycle stream, the costs of lead-free alloys may be prohibitive because of the demand on lead-free scrap. Alternative leaded-copper substitutes under consideration include the bismuth-copper alloys; however, bismuth also has a deleterious effect on other classes of copper alloys. Therefore, a way must also be found to remove bismuth, as well as lead, from the copper scrap stream to successfully implement the new lead-free alloys.

The Basel Convention, negotiated in 1989 under the auspices of the United Nations Environment Program (UNEP), eliminates uncontrolled transboundary movement of hazardous and other wastes between nations, provides for

accountability for waste movement, and encourages self-sufficiency in waste treatment. As currently written, the convention separates recyclables from other waste and recognizes the international community's need to trade in recyclables; however, "hazardous waste" is defined much more broadly than in current U.S. law and regulations. The convention becomes effective 90 days following 20 countries ratifying the document. EC ratification and implementation was not expected until early 1992. Eleven countries had ratified the treaty by yearend 1990. Another 53 countries, including the United States, have signed a United Nations document indicating an interest in ratifying the agreement. Although the United States was a signatory to the convention, the ratification process will take 3 years or more. Because the convention prohibits trade in wastes with nonparticipants, U.S. metal scrap trade with other countries could be limited if the convention is activated prior to U.S. ratification. In addition, the regulatory scheme under Basel could be cumbersome and documents may duplicate existing procedures.

The Organization for Economic Cooperation and Development (OECD) was developing a protocol for issues relating to the convention. A three-tier scheme was proposed that would designate a "green list," requiring no controls other than those normally applied in commercial transactions. Most copper scrap would be included in the "green list." Wastes that would be on an "amber list" would be subject to some restrictions of the Basel Convention and would include most metal ashes, sludges, and residues. Wastes on the "red list" would be subject to most restrictions. No metal wastes are on the latest version of the red list.

Complaints surfaced in the press regarding the use of ferrous scrap waste, such as food cans, to recover copper from leached copper ore. Some critics felt that this process was setting a "dangerous precedent for the use of recycled materials." The process was considered by others as a legitimate use

of steel scraps that would otherwise add to already overloaded garbage dumps and would reduce the amount of mining needed to produce the same amount of copper.¹⁷

Production.—Smelting and Refining.—In the United States, a shift toward refining more scrap has been evident for a number of years, as shown in figure 10. This change was coincidental to a change in wire rod technology that resulted in a requirement for a higher grade of cathode for continuous casting machinery. It also coincided with the growth in smelting and refining in other countries, which served to deprive the United States of sufficient blister and concentrate imports during the 1960's and 1970's. With the exceptions of the Great Depression and World War II, refined copper from scrap was only 7% to 15% of production. Since 1940, the proportion of scrap being refined has increased significantly while the foreign component decreased in equal magnitude. In 1941, 30% of refined production was derived from foreign materials, while about 8% was from scrap. In 1991, only 3.9% of U.S. refined production was from foreign materials, while 21% was from scrap. (See figure 10.)

Ingotmaking.—Some ingotmakers were concerned over the viability of the domestic ingot industry. U.S. brass and bronze ingot production has contracted from about 250,000 tons in the early 1970's to only 162,000 tons in 1991, and may be facing further contraction. The ingot category most severely affected was the leaded-red brass and semired brass ingot alloy group, which has decreased from about 150,000 tons in the early 1970's to only 98,600 tons in 1991. High-leaded tin bronze has also decreased from about 26,000 tons per year in the 1970's to less than 9,000 tons per year since the mid-1980's. However, one major ingotmaker believed that the exacting requirements of new lead-free alloys could stimulate exports of alloy ingot, in lieu of scrap, to offshore foundries that lack the technical expertise

to produce these alloys.¹⁸ This trend would increase demand for already tight supplies of No. 1 copper scrap, while creating a pool of unusable leaded brass scrap.

Foundries and Chemical Plants.—The number of U.S. foundries has diminished over the years, following the fate of the steel, automobile, space, and other industries that they service. Currently numbering about 700, only a few foundries are really large; most foundries are very small operations that cast select parts for many U.S. industries from a wide variety of cast copper alloys. Most copper chemicals are made from scrap, which is leached, formed as cupric and cuprous oxides, and copper sulfate and, eventually, a variety of other copper chemicals. Copper and copper alloy powders are also made from refined copper and copper alloys that were derived from scrap.

Consumption.—In 1991, about 1.6 million tons of copper-base scrap containing an estimated 1.23 million tons of copper was consumed in the United States. The largest scrap categories were: No. 1 copper, 28%; No. 2 copper, 22%; leaded yellow brass, 16%; low-grade ashes and residues, 9%; yellow and low brass, 7%; automobile radiators, 6%; red brass, 4%; and cartridge cases, 4%. A wide variety of alloys made up the remaining 4%. Brass and copper tube mills processed 66% of No. 1 copper and most of the cartridge cases and yellow brass, while the secondary smelters and ingotmakers processed 89% of the No. 2 scrap and most of the auto radiators and red brass scrap. With a few exceptions, U.S. wire rod mills did not consume purchased scrap directly. One U.S. wire rod-producing company constructed a continuous-process scrap refining and wire rod casting plant in which No. 1 return scrap from its own plants was processed.

According to industry sources, the quantity of scrap available during 1991 was the lowest in some time. Along with the generally lower refined copper prices, this was having an impact on scrap

prices, reducing spreads and profits. Observers listed several reasons for the scrap shortage. Normally high during periods of slow economic activity, scrap inventories were low, having been worked down over the long period of healthy prices since 1987. In addition, the slower economy had reduced manufacturing (production of new scrap) and reconstruction (demolition) and thus, the opportunity for generation of old scrap. Manufacturing processes also were becoming more efficient with less generation of scrap. Some observers estimated that the amount of scrap generated by the U.S. industry has declined by more than 50% per manufactured item over the past 20 years. A global shortage of scrap also was stimulating export demand for scrap and further tightening domestic availability. The net result was that, regardless of price, many scrap dealers were at times unable to provide more than one or two trailerloads at a time. It was anticipated that when the economy recovers, scrap supplies may be tight because no stocks will have accumulated during the current slow-growth period.

Markets and Prices.—Scrap prices are related to the refined copper price, but the price spread must be sufficient to allow for processing costs and the inherent costs of scrap preparation (collection, sorting, shipping, chopping, briquetting, etc.). If the spread is too narrow, the copper processor cannot charge enough for the end product, which also is determined by the refined copper price, to compensate and, thus, cannot make a profit. Unlike primary production, where numerous factors combine to keep a mine open at prices below operating costs, scrap processors and dealers need to meet operating costs. At times of high refined copper prices, more copper scrap is offered to processors, if available. On the other hand, if refined prices are low, less scrap material enters the market. The terms that scrap smelters can charge for processing becomes uneconomic as the gap between scrap price and refined price narrows.

Trends for Brass Mill No. 1, Refiners No. 2, and Dealers No. 2 prices are compared with the Commodity Exchange of New York (COMEX) first position price and with the U.S. producers, delivered, refined copper prices from 1970 to 1991 in figure 11. It can be observed that Brass Mill buying prices for No. 1 scrap generally track that of the delivered producers refined price and COMEX first position price, but is generally below them. The No. 2 scrap prices are below these, allowing for differences in processing costs. The spread between refiners buying price for No. 2 scrap and the producers' refined copper price has varied from 9 cents in 1970, 27 cents in 1980, to 21 cents in 1991. The low spreads in the early 1970's were caused by price controls placed on U.S. copper prices during this period. The very high spreads of the late 1980's, as shown in figure 12, which averaged above 30 cents per pound, were the result of high refined copper prices and a good supply of scrap. Prices also tend to widen when speculative interest is active on the futures exchanges, such as is the case when the copper price is high. The spreads have been decreasing since the high point of 1987, as a result of lower refined prices since that time. (See figures 11 and 12.)

In 1991, scrap prices were higher in the first 4 months of the year, but softened beginning in May. By September, scrap prices again recovered, closely paralleling that of refined copper. Scrap prices, like refined prices, were generally lower than those in 1990.

Yearend scrap inventories, as reported to the U.S. Bureau of Mines, at smelters, refiners, ingotmakers, and brass mills decreased from 94,381 tons in 1987 to 85,919 tons in 1991. However, these figures disguise opposing inventory trends between smelters and refineries, which increased from 48,276 tons of copper scrap in 1987 to 53,970 tons at yearend 1991, and brass mills, where scrap inventories decreased markedly from 46,105 tons in 1987 to 31,949 tons at yearend 1991. Scrap consumption trends would also appear to be diverging. In 1991, compared with 1990, scrap

consumption was 3% higher at smelters and refiners (including refiners at copper tube and wire mills), but was 8.4% lower at ingotmakers and 7% lower at brass mills.

Foreign Trade.—U.S. scrap shipments have dominated the international scrap market in recent years, taking advantage of the fall in the value of the dollar against European and Asian currencies since 1986 and relatively cheap freight rates. Trends in U.S. scrap exports are shown in figure 13. In 1991, exports of copper scrap were below the record-high level of 1989. In 1991, 254,028 tons of copper in alloyed and unalloyed copper scrap was exported from the United States, compared with 293,074 tons in 1990. Shipments to China, Japan, and the Republic of Korea, however, posted significant gains. China, in particular, had become a significant purchaser of U.S. scrap compared with previous years. U.S. exports to China had increased from a total of 22,554 tons of copper in unalloyed and alloyed copper scrap in 1990 to 45,582 tons in 1991. (See figure 13.)

World Review.—As a component of world supply, scrap has been increasing at a slightly faster rate than primary copper production. Scrap recovery represented 18% of total world copper supply (primary + scrap) in 1974, but has increased to about 20% of world supply in the 1980's. The Western European countries comprise the largest single market for scrap consumption in the world. France, Germany, Italy, and the United Kingdom are the largest consumers of copper and copper alloy scrap. The United States is second after the EC in scrap consumption. Asia, mostly Japan, is the third largest scrap-consuming area of the world. Scrap consumption in the Asian countries has continued to grow parallel to increased refined copper consumption as these countries have developed their manufacturing industries since the 1960's. In the United States, about 44% of total annual copper consumption was from

copper in old and purchased new scrap. Copper scrap accounted for a similar percentage, 36%, in the countries of the EC, which collectively comprise one of the largest sources of copper scrap in the world.

As shown in figure 14, the United States is the largest exporter of copper scrap in the world, followed by France, Germany, and the United Kingdom. The EC, as a group, makes up the largest single scrap trading area in the world. Nearly all imports and exports from the EC are to or from other European nations. Scrap imports have increased significantly since 1983 in Belgium, Germany, Italy, and the Netherlands. In Italy, the increase since 1985 corresponded with new processing and semifabrication plants constructed during this period. The Asian countries export very little scrap, and most of this goes to other Asian countries. Asian imports of scrap from western countries has grown significantly in recent years. (See figure 14.)

Current Research.—There have been some serious efforts in developing hydrometallurgical processes for secondary copper, some of which have been very successful and are currently being put into place. Bronzes and gun metals have been directly electrorefined into pure copper using complex electrolytes. Investigations have also been conducted for consecutive electrorefining of copper and zinc directly from copper alloy scrap. Some researchers have suggested aqueous $\text{CuCl}_2\text{-NaCl}$ leaching of copper-brass scrap. For large-scale operation, the scrap is leached under vigorous agitation at 90° C at an initial pH of 2. The impurities from the leach liquor were precipitated as oxides, hydroxides, or carbonates by pH adjustment. Pure cuprous solution obtained after filtration was electrolyzed to obtain pure copper powder.¹⁹

An extensive review of the recovery of metals from electronic scrap described several processes currently in use or under investigation.²⁰ The literature on electronic scrap recycling dates to 1969,

when the U.S. Bureau of Mines began to investigate procedures for recovering precious metals from old military scrap, which at that time reportedly totaled more than 9,100 tons per year. The U.S. Bureau of Mines has developed a hydrometallurgical method for processing electronic scrap that consists of a three-stage leach procedure, and which has been developed to a pilot scale. The scrap is mechanically processed, and the fraction that emerges from the high-tension separator is the portion hydrometallurgically treated. This fraction contains most of the gold and silver. It is first leached with sodium hydroxide to remove aluminum and washed and incinerated to remove organics. This is followed by pressure leaching with sulfuric acid to dissolve silver, nickel and copper at higher temperatures (150° C). Silver is leached under pressure with nitric acid and then precipitated with NaCl. Copper is recovered from both nitric and sulfuric acid solutions by cementation with the steel fraction. Essentially all of the gold, silver, and 92% of the copper were recovered from the scrap.

A German patent described the recovery of copper, gold, lead, palladium, silver, and tin from electronic scrap, which also includes plastics (such as in connectors and printed circuits). The scrap is leached with 30% to 50% HNO₃ at 35° C to yield metal nitrates in solution, gold, and SnO₂. After removal of undissolved plastics, the suspension is treated with concentrated sulfuric acid to precipitate sulfate crystals containing gold and tin oxide. After cooling, the sulfates are added to water, forming a copper-, palladium- and silver-containing solution, and the insoluble gold, lead, and tin materials are filtered off. The filtrate is cemented with copper at 40° to 50° C to produce a silver-34% lead alloy. Copper metal is electrodeposited from solution, and the silver palladium alloy is electrorefined to give palladium and silver. The recovery rates for copper, gold, palladium, and silver exceed 97%.²¹

Bell Telephone Laboratories Inc. announced a new lead-free brass alloy, using bismuth and small amounts of tin or

phosphorus. Lead is added to brass to make it malleable and easier to machine. However, lead may leach from the metal and contaminate water in plumbing systems. By adding 1% to 2% bismuth, the machinability was equal to that of lead-copper alloys. This could increase demand for bismuth to about 4,500 tons per year, according to some estimates. World capacity for bismuth production was estimated by the U.S. Bureau of Mines to be almost 8,000 tons per year, but only about 4,000 tons was produced in 1990.²²

Outlook

As discussed in the resource section, the reservoir of unclaimed copper in use is large, but recovery from this base is limited by the following factors: (1) refined copper prices, (2) useful life of products, (3) available recovery technologies, and (4) rate of copper consumption. The average useful life for copper products is about 25 years before being scrapped and entering the market as "old" scrap. New (manufacturing) scrap, on the other hand, has a short life of about 30 days, and its recovery is limited by domestic manufacturing rates and efficiencies. This wide difference in turnaround and availability has resulted in a gradual increase of "new" scrap versus "old" scrap as a component in all scrap collected in the United States since the 1930's. Recently, however, industry sources claim that the amount of new scrap being generated by manufacturing plants has been cut by as much as 50% owing to increased production efficiencies. Although U.S. copper (primary + scrap) consumption will increase in 1992, scrap consumption will remain at about the 1991 level owing to the effects of lower copper prices, increased manufacturing efficiencies, and decreased manufacturing rates during the 1991 recession. In addition, increased exports of scrap to the Far East will cause domestic tightness in available scrap. Because scrap is usually a lower cost alternative to primary metal, it will continue to be of great interest to countries such as China, India, the

Republic of Korea, and Taiwan as they expand their industries.

Over the next decade, copper scrap will remain a premium material of essential use to the U.S. semifabricating industry. Because of its intrinsic value and usefulness, copper scrap of all types has always been extensively recycled. This was particularly true during times of high demand, such as war years. Demand for scrap during those periods was such that scrap export controls were put in place through most of the 1940's, 1950's and 1960's. Export controls on scrap were finally removed in September 1970.

Another factor expected to affect the way copper scrap is collected and processed over the next decade is the legislative limit on lead in copper alloys, to 2% or less of lead. Some in the industry believe that, since the average copper alloy contains about 8% lead, the scrap to be used in the future will have to be diluted. This would mean that No.1 copper could be in greater demand in the future and that the production of these particular alloys will be higher in cost. Following the current decreasing trend, fewer high-lead copper alloys will be produced in the United States within the next decade.

Without successful implementation of new recovery technologies, the recovery of copper in all parts of the economy will be impeded by stricter legislative requirements. New technologies for the recovery of copper from wastewaters, electronic scrap, and other scrap with low copper content will enable more metal to be retrieved. Some solvent extraction plants are already in operation. With increased environmental and labor safety requirements, some types of ingot will be difficult to produce economically. New technologies will be required to decrease the lead content of machinable and other leaded-copper alloys. In addition, new uses must be found for some of the associated products, such as shredded plastics, that are generated in the preparation of copper scrap.

²¹Prepared by John F. Papp, physical scientist, Branch of Metals.

²Prepared by Patricia Plunkert, physical scientist, Branch of Metals.

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⁶Robare, T. J., J. J. Witters, G. M. Kallmeyer, and R. H. Keenan. Recycling of Aluminum-Lithium Alloy Scrap. Paper in *Light Metals 1991*, ed. by E. L. Rooy (120th TMS Annu. Meeting, New Orleans, LA, Feb. 17-21, 1991). TMS-AIME, Warrendale, PA, 1991, pp. 1223-1227.

⁷Prepared by Janice L. W. Jolly, physical scientist, Branch of Metals.

⁸Institute of Scrap Recycling Industries. Scrap Specifications Circular 1988. Guidelines for Nonferrous Scrap: NF-88, 18 pp.

⁹Carrillo, F. V., M. H. Hibshman, and R. D. Rosenkranz. Recovery of Secondary Copper and Zinc in the United States. *BuMines IC 8622*, 1974, 58 pp.

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¹¹Page 36 of work cited in footnote 10.

¹²*Metal Bulletin Monthly*. Grim Outlook for U.S. Ingot Producers. May 1992, p. 17.

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¹⁴Shamsuddin, M. Metal Recovery From Scrap and Waste. *J. of Metals*, Feb. 1986, pp. 24-31.

¹⁵Page 25 of work cited in footnote 14.

¹⁶*American Metal Market*. Vinyl Fluff Tabbed for Recycling. V. 99, No. 77, Apr. 9, 1991, p. 7.

¹⁷*The Washington Post*. How San Francisco's Discarded Cans Are Recycled To Aid Mining in Utah. May 6, 1991, p. A3.

¹⁸Page 17 of work cited in footnote 12.

¹⁹Page 25 of work cited in footnote 14.

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²¹Page 54 of work cited in footnote 20.

²²*Advanced Materials and Processes*. Free-cutting Copper Alloys Contain No Lead. Oct. 1991, pp. 23-27.

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TABLE 1
SALIENT U.S. RECYCLING STATISTICS FOR SELECTED METALS

Year	Recycled metal, ¹ by source of supply					
	Quantity (metric tons)			Value (thousand dollars)		
	New scrap ²	Old scrap ³	Total scrap	New scrap	Old scrap	Total scrap
ALUMINUM⁴						
1987	1,134,000	852,000	1,986,000	1,807,387	1,357,931	3,165,318
1988	1,077,000	1,045,000	2,122,000	2,613,855	2,536,192	5,150,047
1989	1,043,000	1,011,000	2,054,000	2,019,860	1,957,889	3,977,749
1990	1,034,000	1,359,000	2,393,000	1,687,784	2,218,276	3,906,060
1991	979,000	1,522,000	2,501,000	1,283,349	1,995,155	3,278,504
COPPER⁵						
1987	716,122	497,937	1,214,059	1,294,597	900,165	2,194,762
1988	788,712	518,179	1,306,891	2,103,960	1,382,289	3,486,250
1989	760,894	547,561	1,308,455	2,197,502	1,581,385	3,778,886
1990	773,873	535,656	1,309,529	2,098,498	1,452,529	3,551,027
1991*	679,882	533,338	1,213,220	1,661,992	1,281,630	2,943,622
LEAD⁶						
1987	52,535	657,532	710,067	37,630	470,978	508,608
1988	45,274	691,127	736,401	36,162	552,027	588,189
1989	49,612	841,729	891,341	40,611	689,227	729,630
1990	48,104	874,093	922,197	46,185	839,227	885,412
1991	54,172	829,563	883,735	37,978	581,581	619,559
NICKEL⁷						
1987	—	—	32,331	—	—	156,311
1988	—	—	41,039	—	—	565,448
1989	—	—	39,784	—	—	529,452
1990	—	—	33,716	—	—	298,862
1991	—	—	32,520	—	—	265,221
TIN⁸						
1987	4,604	11,462	16,066	42,528	105,878	148,407
1988	3,925	11,350	15,275	38,160	110,348	148,509
1989	2,795	11,545	14,340	32,041	164,394	196,436
1990	4,035	13,200	17,275	34,337	112,329	146,666
1991	NA	NA	NA	NA	NA	NA
ZINC⁹						
1987	270,000	82,000	352,000	249,570	75,796	325,366
1988	240,000	97,000	337,000	318,578	128,759	447,337
1989	230,000	117,000	347,000	415,964	211,600	627,564
1990	232,000	109,000	341,000	381,573	179,273	560,846
1991	233,000	120,000	353,000	271,114	139,629	410,743

*Estimated. NA Not available.

¹Recycled metal is metal recovered from purchased new plus old scrap supply.

²New scrap is scrap that results from the manufacturing process, including metal and alloy production.

³Old scrap is scrap that results from consumer products.

⁴Quantity is the calculated metallic recovery from aluminum-base scrap, estimated for full industry coverage. Value is estimated based on the average annual U.S. market price for primary aluminum metal.

⁵Recoverable copper values in scrap based on annual averages for refined copper.

⁶Transaction value estimated to be LME average cash value plus 6.5 cents/lb.

⁷Nickel scrap is Ni contained in ferrous and nonferrous scrap receipts. Value is average annual LME cash price of Ni cathode.

⁸Value estimated based upon Metals Week Tin Composite price. Data for 1991 are not available because they are being re-evaluated.

⁹Value based on average annual U.S. zinc metal price published in Metals Week (MW); for 1987-90, the MW average prices were based on U.S. or North American Producer's High Grade zinc delivered prices and for 1991, the London Metal Exchange spot prices for Special High Grade zinc plus premiums based on market conditions.

TABLE 2
SALIENT U.S. APPARENT CONSUMPTION AND RECYCLING
STATISTICS FOR SELECTED METALS

	Quantity (metric tons)			Value (thousand dollars)		
	Apparent consumption ¹	Recycle ²	Recycle percent	Apparent consumption ³	Recycle	Recycle percent
ALUMINUM ⁴						
1987	6,603,000	1,986,000	30.08	10,523,964	3,165,318	30.08
1988	6,450,000	2,122,000	32.90	15,654,008	5,150,047	32.90
1989	6,000,000	2,054,000	34.23	11,619,521	3,977,749	34.23
1990	6,298,000	2,393,000	38.00	10,280,136	3,906,060	38.00
1991	6,214,000	2,501,000	40.25	8,145,791	3,278,504	40.25
COPPER ⁵						
1987	2,912,929	1,214,059	42	5,265,960	2,194,762	42
1988	3,002,257	1,306,891	44	8,008,791	3,486,250	44
1989	2,945,209	1,308,455	44	8,505,917	3,778,886	44
1990	2,942,311	1,309,529	45	7,978,614	3,551,027	45
1991*	2,782,942	1,213,220	44	6,687,509	2,943,623	44
LEAD ⁶						
1987	1,259,029	705,305	56.0	895,715	505,197	56.4
1988	1,274,477	735,122	57.7	1,000,132	587,167	58.7
1989	1,382,250	898,851	65.0	1,115,490	735,777	66.0
1990	1,345,344	918,213	68.3	1,277,557	881,588	69.0
1991	1,280,586	898,045	70.1	885,496	629,959	71.1
NICKEL ⁷						
1987	155,781	32,331	20.75	753,155	156,311	20.75
1988	159,019	41,039	25.81	2,191,014	565,448	25.81
1989	135,218	39,784	29.42	1,799,504	529,452	29.42
1990	145,556	33,716	23.16	1,290,223	298,862	23.16
1991	128,048	32,520	25.40	1,044,310	265,221	25.40
TIN ⁸						
1987	59,458	16,066	27	549,234	148,407	27
1988	60,955	15,275	25	592,627	148,509	25
1989	47,285	14,340	30	542,076	164,394	30
1990	53,430	17,275	32	454,680	147,007	32
1991	NA	NA	NA	NA	NA	NA
ZINC ⁹						
1987	1,324,000	352,000	26.6	1,223,821	325,366	26.6
1988	1,340,000	337,000	25.1	1,778,729	447,337	25.1
1989	1,311,000	347,000	26.5	2,370,097	627,564	26.5
1990	1,239,000	341,000	27.5	2,037,795	560,846	27.5
1991	1,134,000	353,000	31.1	1,319,498	410,743	31.1

*Estimated. NA Not available.

¹Apparent consumption is production plus net imports plus stock changes. Production is primary production plus recycle. Net imports are imports minus exports. Apparent consumption is calculated on a contained weight basis.

²Recycle is metal recovered from reported purchased scrap.

³Same as apparent consumption defined above calculated on a monetary value basis.

⁴Monetary values estimated based on the U.S. market price for primary aluminum ingot. Recycle calculated as metal recovered from reported purchased new and old scrap estimated for full industry coverage. Apparent consumption referred to as apparent supply in aluminum tables.

⁵Copper recovered for consumption valued on average annual refined prices.

⁶Lead processors are segregated by primary and secondary producers. This segregation permits inclusion of stock changes in recycle lead supply. Transaction value for U.S. primary production and net imports estimated to be LME average cash value plus 5 cents/lb delivered. Transaction value for U.S. secondary production estimated to be LME average cash value plus 6.5 cents/lb. Stock adjustment value based on actual proportion of stock change to secondary production.

⁷Value of apparent consumption and recycle estimated as average annual LME cash price.

⁸Value estimated based upon Metals Week Composite price. Data for 1991 are not available because they are being re-evaluated.

⁹Value based on average annual U.S. zinc metal price published in Metals Week (MW); for 1987-90, the MW average prices were based on U.S. or North American Producers' High Grade zinc delivered prices and for 1991, the London Metal Exchange spot prices for Special High Grade zinc plus premiums based on market conditions.

TABLE 3
U.S. APPARENT ALUMINUM SUPPLY AND CONSUMPTION

(Thousand metric tons)

	1987	1988	1989	1990	1991
Primary production	3,343	3,944	4,030	4,048	4,121
Change in stocks: ¹					
Aluminum industry	+341	+11	+61	+2	+32
LME stocks in U.S. warehouses	—	—	—	—	-168
Imports	1,850	1,620	1,470	1,514	1,490
Secondary recovery: ²					
New scrap	1,134	1,077	1,043	1,034	979
Old scrap	852	1,045	1,011	1,359	1,522
Total supply	7,520	7,697	7,615	7,957	7,976
Less total exports	917	1,247	1,615	1,659	1,762
Apparent aluminum supply available for domestic manufacturing	6,603	6,450	6,000	6,298	6,214
Apparent consumption ³	5,469	5,373	4,957	5,264	5,235

¹Revised.

²Positive figure indicates a decrease in stocks; negative figure indicates an increase in stocks.

³Metallic recovery from purchased, tolled, or imported new and old aluminum scrap expanded for full industry coverage.

⁴Apparent aluminum supply available for domestic manufacturing less recovery from purchased new scrap (a measure of consumption in manufactured end products).

TABLE 4
U.S. CONSUMPTION OF AND RECOVERY FROM PURCHASED NEW AND OLD ALUMINUM SCRAP,¹ BY CLASS

(Metric tons)

Class	Consumption	Calculated recovery	
		Aluminum	Metallic
1990			
Secondary smelters	982,011	800,918	860,902
Primary producers	1,212,392	1,015,852	1,085,483
Fabricators	238,331	198,470	223,310
Foundries	71,626	58,893	63,531
Chemical producers	57,017	45,251	45,578
Total	2,561,377	2,119,384	2,278,804
Estimated full industry coverage	2,690,000	2,225,000	2,393,000
1991			
Secondary smelters	1,080,107	878,769	942,364
Primary producers	1,260,752	1,055,742	1,125,035
Fabricators	237,224	196,511	221,184
Foundries	77,700	64,670	69,650
Chemical producers	30,953	21,057	21,332
Total ²	2,686,735	2,216,749	2,379,564
Estimated full industry coverage	2,825,000	2,329,000	2,501,000

¹Excludes recovery from other than aluminum-base scrap.

²Data may not add to totals shown because of independent rounding.

TABLE 5
U.S. STOCKS, RECEIPTS, AND CONSUMPTION OF PURCHASED NEW
AND OLD ALUMINUM SCRAP¹ AND SWEATED PIG IN 1991

(Metric tons)

Class of consumer and type of scrap	Stocks, Jan. 1	Net receipts ²	Consump- tion	Stocks, Dec. 31
Secondary smelters:				
New scrap:				
Solids	5,676	106,040	106,112	5,604
Borings and turnings	5,689	101,355	101,601	5,443
Dross and skimmings	3,395	41,901	43,234	2,062
Other ³	4,506	116,367	115,782	5,091
Total	19,266	365,663	366,729	18,200
Old scrap:				
Castings, sheet, clippings	16,576	407,598	406,634	17,540
Aluminum-copper radiators	576	9,934	9,741	769
Aluminum cans ⁴	6,032	242,992	241,187	7,837
Other ³	426	45,276	45,367	335
Total⁶	23,610	705,800	702,928	26,481
Sweated pig	956	10,121	10,449	628
Total secondary smelters⁶	43,832	1,081,584	1,080,107	45,309
Primary producers, foundries, fabricators, chemical plants:				
New scrap:				
Solids	10,823	408,067	405,716	13,174
Borings and turnings	61	26,665	26,540	186
Dross and skimmings	1,416	21,081	21,700	797
Other ³	4,148	207,072	204,100	7,120
Total	16,448	662,885	658,056	21,277
Old scrap:				
Castings, sheet, clippings	1,781	219,716	219,592	1,905
Aluminum-copper radiators	85	38,805	38,865	25
Aluminum cans	21,037	679,384	672,596	27,825
Total	22,903	937,905	931,053	29,755
Sweated pig	833	17,884	17,520	1,197
Total primary producers, etc.	40,184	1,618,674	1,606,629	52,229
All scrap consumed:				
New scrap:				
Solids	16,499	514,107	511,828	18,778
Borings and turnings	5,751	128,020	128,141	5,629
Dross and skimmings	4,811	62,982	64,934	2,859
Other	8,654	323,439	319,882	12,211
Total new scrap	35,715	1,028,548	1,024,785	39,477
Old scrap:				
Castings, sheet, clippings	18,357	627,314	626,226	19,445
Aluminum-copper radiators	661	48,739	48,606	794
Aluminum cans	27,069	922,376	913,783	35,662

See footnotes at end of table.

TABLE 5—Continued
**U.S. STOCKS, RECEIPTS, AND CONSUMPTION OF PURCHASED NEW
 AND OLD ALUMINUM SCRAP¹ AND SWEATED PIG IN 1991**

(Metric tons)

Class of consumer and type of scrap	Stocks, Jan. 1	Net receipts ²	Consump- tion	Stocks, Dec. 31
All scrap consumed—Continued:				
Old scrap—Continued:				
Other	426	45,276	45,367	335
Total old scrap ⁶	<u>46,513</u>	<u>1,643,705</u>	<u>1,633,981</u>	<u>56,236</u>
Sweated pig	1,788	28,005	27,969	1,825
Total of all scrap consumed ⁶	<u>84,016</u>	<u>2,700,258</u>	<u>2,686,735</u>	<u>97,538</u>

¹Revised.

¹Includes imported scrap. According to reporting companies, 3.60% of total receipts of aluminum-base scrap, or 97,228 metric tons, was received on toll arrangements.

²Includes inventory adjustment.

³Includes data on foil, can stock clippings, and other miscellaneous.

⁴Used beverage cans toll treated for primary producers are included in secondary smelter tabulation.

⁵Includes municipal wastes (includes litter) and fragmentized scrap (auto shredder).

⁶Data may not add to totals shown because of independent rounding.

TABLE 6
PRODUCTION AND SHIPMENTS OF SECONDARY ALUMINUM ALLOYS BY INDEPENDENT SMELTERS IN THE UNITED STATES

(Metric tons)

	1990		1991	
	Production	Net shipments ¹	Production	Net shipments ¹
Die-cast alloys:				
13% Si, 360, etc. (0.6% Cu, maximum)	60,935	61,918	60,690	59,909
380 and variations	273,432	272,270	308,968	310,083
Sand and permanent mold:				
95/5 Al-Si, 356, etc. (0.6% Cu, maximum)	16,618	16,606	12,587	12,653
No. 12 and variations	W	W	W	W
No. 319 and variations	57,284	55,577	49,308	51,491
F-132 alloy and variations	8,693	11,279	13,770	17,294
Al-Mg alloys	695	700	723	719
Al-Zn alloys	2,648	2,489	2,761	2,789
Al-Si alloys (0.6% to 2.0% Cu)	11,896	11,906	8,608	8,420
Al-Cu alloys (1.5% Si, maximum)	1,753	1,745	1,195	1,249
Al-Si-Cu-Ni alloys	1,174	1,178	1,278	1,272
Other	1,468	1,357	890	1,006
Wrought alloys: Extrusion billets	125,604	125,937	67,922	68,827
Miscellaneous:				
Steel deoxidation	4,866	5,437	6,690	6,690
Pure (97.0% Al)	29	29	117	4,865
Aluminum-base hardeners	1,478	1,520	100	445
Other ²	34,407	34,787	29,060	27,571
Total	602,980	604,735	564,667	575,283
Less consumption of materials other than scrap:				
Primary aluminum	43,336	—	15,881	—
Primary silicon	29,127	—	26,979	—
Other	3,320	—	1,888	—
Net metallic recovery from aluminum scrap and sweated pig consumed in production of secondary aluminum ingot³	527,197	XX	519,919	XX

W Withheld to avoid disclosing company proprietary data; included with "Sand and permanent mold: Other." XX Not applicable.

¹Includes inventory adjustments.

²Includes other die-cast alloys and other miscellaneous.

³No allowance made for melt-loss of primary aluminum and alloying ingredients.

TABLE 7
U.S. EXPORTS OF ALUMINUM SCRAP, BY COUNTRY

Country	Remelt scrap ingot		Used beverage container scrap		Other aluminum waste and scrap		Total ¹	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1990:								
Belgium	—	—	201	\$192	2,494	\$3,570	2,694	\$3,762
Brazil	5	\$23	188	218	2,854	4,002	3,047	4,243
Canada	—	—	385	444	49,288	62,233	49,674	62,677
China	199	323	—	—	3,382	2,688	3,581	3,011
Finland	299	464	—	—	1,145	1,049	1,444	1,513
France	1,570	1,690	—	—	12,247	13,656	13,817	15,347
Germany	2,069	3,099	—	—	3,452	4,806	5,521	7,905
Hong Kong	141	215	—	—	1,376	1,654	1,517	1,868
Italy	125	156	19	13	4,071	4,738	4,215	4,906
Japan	94,413	157,303	1,187	2,447	238,434	322,710	334,034	482,460
Korea, Republic of	941	1,203	42	70	22,368	27,153	23,351	28,426
Mexico	3,312	3,270	429	564	17,061	19,480	20,802	23,314
Netherlands	1,842	3,013	79	73	5,422	7,398	7,344	10,483
Norway	—	—	—	—	1,174	1,600	1,174	1,600
Philippines	78	165	—	—	840	570	918	735
South Africa, Republic of	—	—	—	—	967	256	967	256
Taiwan	7,588	9,100	121	152	48,198	47,544	55,907	56,795
Thailand	1,003	1,572	—	—	260	793	1,263	2,365
U.S.S.R.	—	—	—	—	—	—	—	—
United Kingdom	71	92	123	117	1,865	1,954	2,059	2,163
Other	596	725	80	101	3,310	4,389	3,986	5,215
Total¹	114,250	182,412	2,854	4,389	420,207	532,241	537,312	719,041
1991:								
Belgium	—	—	—	—	176	165	176	165
Brazil	19	94	1	14	3,812	4,055	3,832	4,163
Canada	—	—	100	88	42,983	47,665	43,082	47,752
China	80	99	12	12	3,351	3,278	3,443	3,389
Finland	—	—	—	—	1,365	1,198	1,365	1,198
France	339	431	(²)	3	9,456	9,522	9,796	9,955
Germany	571	839	52	71	1,586	1,679	2,208	2,589
Hong Kong	357	415	—	—	3,601	2,352	3,958	2,767
Italy	—	—	—	—	985	1,328	985	1,328
Japan	86,416	129,421	841	897	167,668	198,992	254,926	329,310
Korea, Republic of	2,402	2,419	294	276	30,230	32,774	32,926	35,470
Mexico	6,875	7,125	171	161	17,532	18,682	24,578	25,968
Netherlands	42	53	125	142	1,586	2,364	1,753	2,558
Norway	—	—	—	—	160	235	160	235
Philippines	21	32	4	6	154	345	178	382
South Africa, Republic of	—	—	—	—	111	128	111	128
Taiwan	8,915	8,248	160	602	56,082	49,953	65,157	58,803
Thailand	2,020	2,766	—	—	107	354	2,126	3,120
U.S.S.R.	—	—	—	—	—	—	—	—

See footnotes at end of table.

TABLE 7—Continued
U.S. EXPORTS OF ALUMINUM SCRAP, BY COUNTRY

Country	Remelt scrap ingot		Used beverage container scrap		Other aluminum waste and scrap		Total ¹	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1991—Continued:								
United Kingdom	334	\$599	826	\$805	2,197	\$2,267	3,356	\$3,671
Other	1,347	2,106	220	791	5,138	5,852	6,705	8,749
Total ¹	109,738	154,645	2,805	3,867	348,277	383,189	460,820	541,702

¹Data may not add to totals shown because of independent rounding.

²Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF ALUMINUM SCRAP, BY COUNTRY

Country	Remelt scrap ingot		Used beverage container scrap		Other aluminum waste and scrap		Total ¹	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1990:								
Argentina	82	\$108	—	—	—	—	82	\$108
Australia	62	107	—	—	—	—	62	107
Bahamas	—	—	100	\$67	488	\$215	589	283
Bermuda	—	—	86	57	—	—	86	57
Brazil	255	481	—	—	19	23	274	504
Canada	7,302	10,723	23,498	25,391	132,736	171,113	163,536	207,227
China	20	29	15	5	—	—	35	34
Colombia	—	—	185	173	545	555	730	728
Germany	344	521	—	—	77	156	421	677
Guatemala	8	7	50	39	259	242	317	288
Honduras	—	—	214	76	12	10	226	86
Jamaica	—	—	—	—	1,265	1,341	1,265	1,341
Japan	—	—	—	—	65	235	65	235
Mexico	—	—	9,024	8,876	19,805	18,870	28,830	27,747
New Zealand	53	90	13	14	—	—	66	104
Panama	108	128	1,413	1,360	1,071	1,177	2,592	2,665
South Africa, Republic of	127	148	—	—	—	—	127	148
Spain	69	95	—	—	—	—	69	95
Taiwan	408	591	—	—	—	—	408	591
U.S.S.R.	2,627	3,766	—	—	—	—	2,627	3,766
Venezuela	1,205	1,794	2,271	2,131	5,177	6,097	8,652	10,021
Other	—	—	157	136	2,980	2,727	3,137	2,863
Total ¹	12,670	18,589	37,028	38,325	164,499	202,761	214,196	259,674
1991:								
Argentina	—	—	—	—	—	—	—	—
Australia	—	—	—	—	337	331	337	331
Bahamas	—	—	53	54	1,425	229	1,479	282
Bermuda	—	—	44	37	14	8	57	45
Brazil	—	—	—	—	—	—	—	—

See footnotes at end of table.

TABLE 8—Continued
U.S. IMPORTS FOR CONSUMPTION OF ALUMINUM SCRAP, BY COUNTRY

Country	Remelt scrap ingot		Used beverage container scrap		Other aluminum waste and scrap		Total ¹	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1991—Continued:								
Canada	3,206	\$4,192	21,819	\$20,581	128,744	\$148,263	153,769	\$173,036
China	—	—	—	—	44	9	44	9
Colombia	—	—	197	204	266	307	463	511
Germany	560	649	—	—	363	703	923	1,352
Guatemala	—	—	48	32	358	212	406	244
Honduras	—	—	34	14	124	135	157	148
Jamaica	—	—	—	—	774	499	774	499
Japan	—	—	—	—	102	385	102	385
Mexico	222	161	6,264	5,653	20,743	17,071	27,230	22,885
New Zealand	—	—	—	—	—	—	—	—
Panama	37	38	963	763	993	937	1,993	1,738
South Africa, Republic of	—	—	—	—	—	—	—	—
Spain	99	111	—	—	16	8	116	119
Taiwan	—	—	—	—	89	110	89	110
U.S.S.R.	806	1,036	—	—	10	2	816	1,038
Venezuela	458	517	2,004	1,637	5,099	3,986	7,560	6,140
Other	2,781	3,208	177	116	9,113	7,362	12,070	10,686
Total¹	8,170	9,912	31,602	29,090	168,612	180,556	208,384	219,558

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

**TABLE 9
COPPER RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY**

(Metric tons)

	1987	1988	1989	1990	1991
KIND OF SCRAP					
New scrap:					
Copper-base	689,999	764,490	737,088	750,707	658,060
Aluminum-base	25,871	24,104	23,761	23,124	21,775
Nickel-base	240	118	45	42	47
Zinc-base	12	—	—	—	—
Total	716,122	788,712	760,894	773,873	679,882
Old scrap:					
Copper-base	481,460	498,797	530,499	*502,326	495,397
Aluminum-base	16,401	19,271	16,957	33,227	37,858
Nickel-base	70	86	78	77	61
Zinc-base	6	25	27	*26	22
Total	497,937	518,179	547,561	*535,656	533,338
Grand total	1,214,059	1,306,891	1,308,455	*1,309,529	1,213,220
FORM OF RECOVERY					
As unalloyed copper:					
At electrolytic plants	311,312	347,442	376,595	328,196	318,182
At other plants	112,445	109,036	112,687	121,705	107,905
Total	423,757	456,478	489,282	449,901	426,087
In brass and bronze	736,725	800,221	*774,770	*800,720	725,714
In alloy iron and steel	973	763	*630	578	572
In aluminum alloys	47,932	45,632	41,719	*55,496	58,706
In other alloys	506	327	*106	*112	118
In chemical compounds	4,166	3,470	1,948	2,720	2,021
Total¹	790,302	850,413	819,173	*859,628	787,133
Grand total	1,214,059	1,306,891	1,308,455	*1,309,529	1,213,220

*Revised.

¹Data may not add to totals shown because of independent rounding.

**TABLE 10
COPPER RECOVERED AS REFINED COPPER AND IN ALLOYS AND OTHER FORMS FROM COPPER-BASE SCRAP PROCESSED IN THE UNITED STATES, BY TYPE OF OPERATION**

(Metric tons)

Type of operation	From new scrap		From old scrap		Total ¹	
	1990	1991	1990	1991	1990	1991
Ingotmakers	*19,963	37,598	*124,136	90,767	*144,098	128,365
Refineries ²	129,247	111,452	311,510	306,309	440,757	417,761
Brass and wire rod mills	570,025	490,820	32,626	69,327	602,651	560,148
Foundries and manufacturers	*31,156	17,832	31,650	27,329	*62,806	45,161
Chemical plants	316	358	2,404	1,665	2,720	2,021
Total¹	750,707	658,060	*502,326	495,397	*1,253,032	1,153,456

*Revised.

¹Data may not add to totals shown because of independent rounding.

²Electrolytically refined and fire-refined scrap based on source of material at smelter level.

**TABLE 11
PRODUCTION OF SECONDARY COPPER AND COPPER-ALLOY
PRODUCTS IN THE UNITED STATES, BY ITEM PRODUCED FROM
SCRAP**

(Metric tons)

Item produced from scrap	1990	1991
UNALLOYED COPPER PRODUCTS		
Electrolytically refined copper	328,196	318,182
Fire-refined copper	112,561	99,575
Copper powder	8,525	7,794
Copper castings	618	536
Total¹	449,901	426,087
ALLOYED COPPER PRODUCTS		
Brass and bronze ingots:		
Tin bronzes	15,619	15,240
Leaded red brass and semired brass	117,747	98,666
High-leaded tin bronze	9,022	7,965
Yellow brass	6,962	6,278
Manganese bronze	10,266	7,020
Aluminum bronze	8,968	7,433
Nickel silver	2,986	2,728
Silicon bronze and brass	5,200	5,415
Copper-base hardeners and master alloys	10,379	7,098
Miscellaneous	3,881	4,344
Total¹	191,031	162,187
Brass mill and wire rod mill products	744,224	609,262
Brass and bronze castings	55,773	39,468
Brass powder	288	238
Copper in chemical products	2,720	2,021
Grand total¹	1,443,938	1,239,263

¹Data may not add to totals shown because of independent rounding.

**TABLE 12
COMPOSITION OF SECONDARY COPPER-ALLOY PRODUCTION IN THE UNITED STATES**

(Metric tons)

	Copper	Tin	Lead	Zinc	Nickel	Aluminum	Total ¹
Brass and bronze ingot production:²							
1990	¹ 154,151	¹ 5,907	¹ 10,420	² 20,124	397	32	191,031
1991	129,450	5,310	9,098	17,939	365	23	162,186
Secondary metal content of brass mill products:							
1990	³ 603,742	288	4,321	133,209	2,645	19	⁴ 744,224
1991	³ 499,594	294	3,850	103,405	W	W	⁴ 609,262
Secondary metal content of brass and bronze castings:							
1990	⁴ 49,755	1,116	1,749	2,954	63	131	⁵ 55,768
1991	34,035	787	1,449	2,908	119	169	39,468

¹Revised. W Withheld to avoid disclosing company proprietary data.

²Data may not add to totals shown because of independent rounding.

³About 96% from scrap and 4% from other than scrap in 1990 and in 1991.

⁴Includes copper recovered from scrap at wire mills to avoid disclosing company proprietary data.

TABLE 13
CONSUMPTION OF COPPER-BASE SCRAP IN 1991¹

(Metric tons, gross weight)

Scrap type and processor	January	February	March	April	May	June	July	August	September	October	November	December	Total
No. 1 wire and heavy:													
Smelters, refiners, and ingotmakers	12,972	9,284	11,166	11,954	12,308	13,734	6,355	10,281	8,440	10,055	6,572	8,814	121,935
Brass and wire rod mills	27,351	23,412	24,194	22,096	22,318	22,176	19,094	23,929	26,575	26,493	26,624	19,216	283,478
Foundries and other manufactures	2,115	2,115	2,115	2,115	2,115	2,115	2,115	2,115	2,115	2,115	2,115	2,115	25,377
No. 2 mixed heavy and light:													
Smelters, refiners, and ingotmakers	27,004	22,998	26,159	28,148	22,752	21,056	21,996	25,502	17,728	28,960	31,072	24,698	298,073
Brass and wire rod mills	1,722	3,236	3,093	2,954	1,918	2,923	2,488	3,648	3,015	3,377	3,093	2,940	34,407
Foundries and other manufactures	248	248	248	248	248	248	248	248	248	248	248	248	2,976
Total unalloyed scrap:													
Smelters, refiners, and ingotmakers	39,976	32,282	37,325	40,103	35,060	34,790	28,351	35,783	26,168	39,016	37,644	33,511	420,009
Brass mills	29,073	26,648	27,288	25,050	24,236	25,099	21,583	27,577	29,591	29,870	29,716	22,157	317,888
Foundries and other manufactures	2,362	2,362	2,362	2,362	2,362	2,362	2,362	2,362	2,362	2,362	2,362	2,362	28,344
Red brass:²													
Smelters, refiners, and ingotmakers	3,979	3,936	4,249	4,151	4,252	4,065	3,042	4,218	3,974	3,666	3,675	2,973	46,180
Brass mills	605	646	602	556	520	569	367	687	485	527	481	445	6,490
Foundries and other manufactures	788	788	788	788	788	788	788	788	788	788	788	788	9,456
Leaded yellow brass:													
Smelters, refiners, and ingotmakers	1,878	1,759	1,880	2,162	2,028	1,862	1,444	1,962	1,974	2,155	1,784	1,246	22,134
Brass mills	18,074	16,415	16,498	17,142	18,650	18,713	16,942	20,541	19,534	20,449	19,864	17,439	220,261
Foundries and other manufactures	238	238	238	238	238	238	238	238	238	238	238	238	2,856
Yellow and low brass:													
All plants	8,107	9,090	9,695	9,305	8,975	9,337	6,654	9,583	7,445	9,939	9,988	7,982	106,100
Cartridge cases and brass:													
All plants	5,807	5,772	5,445	6,015	4,147	4,420	3,070	4,625	4,256	4,395	4,834	3,282	56,068
Auto radiators:													
Smelters, refiners, and ingotmakers	7,339	6,687	8,048	7,865	7,972	6,229	5,516	6,479	5,742	7,090	6,646	5,880	81,493
Foundries and other manufactures	594	594	594	594	594	594	594	594	594	594	594	594	7,128
Bronzes:													
Smelters, refiners, and ingotmakers	919	1,076	1,188	1,355	1,373	1,652	1,091	1,320	1,436	1,220	1,091	846	14,567
Brass mills	514	561	422	515	507	426	403	436	486	661	589	596	6,116
Nickel-copper alloys:													
All plants	1,888	2,110	1,613	1,585	1,657	1,680	1,125	1,341	1,321	1,249	1,401	982	17,952
Low grade & residues:													
Smelters, refiners and other manufacturers	14,81	13,992	15,269	12,702	10,741	10,503	11,183	10,202	9,077	11,133	10,890	10,747	141,250

See footnotes at end of table.

TABLE 13—Continued
CONSUMPTION OF COPPER-BASE SCRAP IN 1991¹

(Metric tons, gross weight)

Scrap type and processor	January	February	March	April	May	June	July	August	September	October	November	December	Total
Other alloy scrap:²													
Smelters, refiners, and ingotmakers	3,101	1,929	3,276	3,814	3,712	2,686	3,451	3,239	3,031	4,147	4,851	3,792	41,029
Brass mills and other manufacturers	691	586	641	718	604	609	529	552	665	787	720	590	7,692
Total alloyed scrap:													
Smelters, refiners, and ingotmakers	34,874	32,243	37,093	35,433	33,616	29,946	28,507	30,707	27,459	32,723	31,465	28,064	382,130
Brass mills	32,181	31,660	31,076	31,795	30,865	32,148	25,652	33,820	31,310	34,036	34,692	28,077	377,312
Foundries and other manufacturers	2,278	2,278	2,278	2,278	2,278	2,278	2,278	2,278	2,278	2,278	2,278	2,278	27,336
Total scrap:													
Smelters, refiners, and ingotmakers	74,850	64,525	74,418	75,535	68,676	64,737	56,858	66,490	53,627	71,739	69,109	61,575	802,139
Brass and wire rod mills	61,254	58,308	58,364	56,845	55,101	57,247	47,235	61,397	60,900	63,907	64,408	50,234	695,200
Foundries and other manufacturers	4,640	4,640	4,640	4,640	4,640	4,640	4,640	4,640	4,640	4,640	4,640	4,640	55,680

¹Data may not add to totals shown because of independent rounding.

²Includes composition turnings, silicon bronze, zinc bronze, railroad car boxes, corks and faucets, gilding metal, and commercial bronze.

³Includes refinery brass, beryllium copper, phosphor copper, and aluminum bronze.

TABLE 14
CONSUMPTION OF PURCHASED COPPER-BASE SCRAP¹

(Metric tons, gross weight)

Period	Smelters and refineries		Ingotmakers		Brass and wire rod mills		Foundries, etc.		Total scrap used
	New scrap	Old scrap	New scrap	Old scrap	New scrap	Old scrap	New scrap*	Old scrap*	
January	14,547	42,734	4,207	13,361	54,772	6,482	1,800	2,800	140,703
February	13,285	34,652	4,741	11,846	51,788	6,520	1,800	2,800	127,432
March	14,678	42,233	4,656	12,851	51,126	7,238	1,800	2,800	137,382
April	13,809	43,567	4,842	13,317	50,030	6,815	1,800	2,800	136,980
May	13,958	36,674	4,832	13,211	48,810	6,291	1,800	2,800	128,376
June	12,290	36,246	4,936	11,264	50,201	7,046	1,800	2,800	126,583
July	11,694	32,007	3,906	9,251	42,272	4,963	1,800	2,800	108,693
August	15,685	34,526	4,728	11,551	53,954	7,443	1,800	2,800	132,487
September	12,412	25,085	4,392	11,738	54,065	6,836	1,800	2,800	119,128
October	15,529	40,200	3,878	12,132	57,575	6,332	1,800	2,800	140,246
November	12,822	42,093	3,654	10,540	57,050	7,357	1,800	2,800	138,116
December	14,575	36,321	3,609	7,070	45,764	4,470	1,800	2,800	116,409
Year total	165,284	446,338	52,381	138,132	617,407	77,793	21,820	33,862	1,553,017

*Estimated.

¹Consumption at brass and wire rod mills assumed equal to receipts.

TABLE 15
CLOSING STOCKS OF COPPER-BASE SCRAP IN 1991

(Metric tons, gross weight)

Scrap type and processor	January	February	March	April	May	June	July	August	September	October	November	December
Smelters, refiners, and ingotmakers:												
Unalloyed scrap:												
No. 1 wire and heavy	3,519	3,888	3,768	4,185	4,439	3,457	6,282	6,317	7,308	4,705	7,152	7,222
No. 2 mixed heavy and light	13,970	12,181	10,257	12,450	11,546	8,653	11,184	11,856	16,235	19,550	14,672	14,566
Total unalloyed scrap	17,489	16,069	14,025	16,635	15,985	12,110	17,466	18,153	23,543	24,255	21,824	21,788
Alloyed scrap:												
Red brass ¹	2,152	1,959	2,020	2,036	1,945	1,752	2,390	2,181	2,163	2,388	2,768	2,556
Leaded yellow brass	1,085	923	994	949	1,028	1,065	1,306	1,389	1,354	1,339	1,324	1,033
Yellow and low brass ²	946	873	758	770	892	827	823	836	943	944	1,119	966
Auto radiators	2,728	2,538	2,257	2,405	2,325	1,456	1,643	1,551	2,022	2,489	2,210	2,142
Bronzes	964	918	987	916	987	1,286	1,103	1,075	931	1,089	948	1,140
Nickel-copper alloys	346	352	317	290	260	341	238	235	211	211	200	253
Low grade and residues	16,704	16,261	15,418	15,621	14,386	14,200	13,635	15,655	17,195	16,714	19,092	19,587
Other alloy scrap ³	2,096	2,512	2,023	1,537	1,669	2,302	1,394	2,353	3,196	4,566	4,227	4,701
Total alloy scrap	27,021	26,336	24,774	24,524	23,492	23,229	22,532	25,275	28,015	29,740	31,888	32,378
Total scrap	44,510	42,405	38,799	41,159	39,477	35,339	39,998	43,428	51,558	53,995	53,712	54,166
Brass and wire rod mills:												
Unalloyed scrap	12,161	12,297	12,064	11,289	11,078	11,268	11,354	11,121	11,763	11,398	12,390	11,001
Alloyed scrap	26,150	24,546	21,647	22,851	21,767	21,555	22,627	24,343	21,291	23,244	21,736	21,483
Total scrap ⁴	38,311	36,843	33,711	34,140	32,845	32,823	33,981	35,464	33,054	34,642	34,126	32,484
Foundries and other manufacturers: ⁵												
Unalloyed scrap	2,635	2,635	2,635	2,635	2,635	2,635	2,635	2,635	2,635	2,635	2,635	2,635
Alloyed scrap	6,258	6,258	6,258	6,258	6,258	6,258	6,258	6,258	6,258	6,258	6,258	6,258
Total scrap	8,893	8,893	8,893	8,893	8,893	8,893	8,893	8,893	8,893	8,893	8,893	8,893
All plants:												
Unalloyed scrap	32,285	31,001	28,724	30,560	29,699	26,013	31,456	31,910	37,942	38,288	36,849	35,425
Alloyed scrap	59,428	57,140	52,680	53,633	51,519	51,041	51,418	55,876	55,564	59,222	59,883	60,118
Total scrap ⁶	91,713	88,141	81,404	84,193	81,218	77,054	82,874	87,786	93,506	97,510	96,732	95,543

¹Includes competition turnings, silicon bronze, zinc bronze, railroad cut boxes, cocks and faucets, gilding metal, and commercial bronze.

²Includes cartridge cases and brass.

³Includes refinery brass, beryllium copper, phosphor copper, and aluminum bronze.

⁴Data may not add to total shown because of independent rounding.

⁵Stocks for Jan.-Nov. estimated based on stocks at end of year.

TABLE 16
FOUNDRIES AND MISCELLANEOUS MANUFACTURERS CONSUMPTION OF BRASS INGOT AND REFINED
COPPER AND COPPER SCRAP IN THE UNITED STATES, BY GEOGRAPHIC DIVISION AND STATE

(Metric tons)

Geographic division and State	Tin bronzes	Leaded red brass and semi-red brass	Yellow, leaded and low brass ¹	Manganese bronze	Nickel silver ²	Aluminum bronze	Hardeners and master alloys ³	Total brass ingot ⁴	Refined copper consumed	Copper scrap consumed
1987	31,178	78,930	7,370	7,435	2,187	5,559	3,221	135,879	40,536	66,909
1988	33,333	89,026	8,669	6,661	1,958	7,592	3,929	151,169	46,411	60,706
1989	34,367	85,752	7,811	6,594	1,654	5,593	3,661	145,434	41,471	64,068
1990	38,150	78,302	7,433	5,672	1,849	5,062	3,269	139,737	46,149	72,811
1991:										
Atlantic:										
Middle: New Jersey, New York, Pennsylvania	5,326	9,346	577	590	78	438	49	16,404	5,702	9,484
South: Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	7,211	3,048	259	270	189	356	17	11,350	10,487	1,071
Central:										
East North: Illinois, Indiana, Michigan, Ohio, Wisconsin	17,224	25,953	2,643	2,195	620	1,750	2,298	52,682	10,345	24,284
South: Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	3,795	10,914	296	239	10	387	114	15,754	6,754	3,037
West North: Iowa, Kansas, Minnesota, Missouri, Nebraska	1,685	4,290	1,202	397	—	781	75	8,431	2,481	3,283
Mountain and Pacific:										
Arizona, California, Colorado, Idaho, Montana, Oregon, Utah, Washington, Wyoming	1,409	7,684	1,950	640	11	832	116	12,643	1,208	11,947
New England: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island	552	700	513	186	270	335	57	2,613	983	456
Undistributed	—	—	—	—	—	—	—	—	26	13
Total⁴	37,202	61,935	7,440	4,517	1,178	4,879	2,726	119,877	37,986	53,575

¹Revised.

²Includes silicon bronze and brass.

³Includes copper nickel and nickel bronze and brass.

⁴Includes special alloys.

⁵Data may not add to totals shown because of independent rounding.

TABLE 17
MONTHLY AVERAGE PRICES FOR COPPER SCRAP AND ALLOY-INGOT, BY TYPE

(Cents per pound)

Year and month	Brass mills No. 1 scrap	Refiners		Dealers' buying (New York)		Alloy-ingot (New York)	
		No. 1 scrap	No. 2 scrap	No. 2 scrap	Red brass turnings and borings	No. 115 brass (85-5-5-5)	Yellow brass (405)
1990:							
January	101.16	96.34	86.66	74.11	58.81	117.86	113.61
February	102.93	97.15	87.78	68.50	54.50	117.50	113.25
March	116.84	110.15	96.23	78.05	57.23	118.59	114.34
April	118.07	111.43	102.40	87.00	61.50	129.50	118.25
May	116.11	109.75	101.41	87.00	61.50	129.50	118.25
June	112.02	105.45	96.60	83.38	60.60	129.50	118.25
July	116.79	109.17	99.77	83.00	60.64	129.50	118.25
August	112.85	115.78	103.86	85.50	62.50	124.20	121.38
September	121.68	114.32	101.62	91.74	69.66	124.50	122.75
October	114.79	107.38	96.13	88.41	70.50	124.50	122.75
November	109.54	103.75	93.35	84.03	69.68	124.50	122.75
December	106.79	101.60	93.10	82.00	69.00	124.50	122.75
Average	112.46	106.86	96.58	82.73	63.01	124.51	118.88
1991:							
January	105.83	101.73	93.17	82.00	69.00	124.50	122.75
February	105.80	102.26	93.23	79.50	62.00	124.50	125.75
March	106.42	103.06	94.47	90.47	62.90	124.50	125.75
April	106.85	103.37	94.70	91.12	63.00	124.50	125.75
May	98.76	94.79	83.13	78.50	61.90	123.70	121.48
June	96.78	92.46	80.36	72.35	57.12	122.00	118.75
July	97.75	93.65	85.41	81.36	66.00	122.00	118.75
August	99.09	96.38	87.14	83.32	56.00	122.00	118.75
September	102.83	99.40	89.51	85.51	56.80	122.00	118.75
October	103.43	100.32	89.73	85.73	58.00	122.00	118.75
November	102.64	98.84	88.22	84.22	58.00	122.00	118.75
December	99.44	92.30	83.74	80.13	57.14	122.00	118.75
Average	101.89	98.21	88.57	82.85	60.66	122.98	121.06

Source: American Metal Market.

TABLE 18
U.S. EXPORTS OF COPPER SCRAP, BY COUNTRY

Country	Unalloyed copper scrap				Copper-alloy scrap			
	1990		1991		1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Belgium	365	\$336	94	\$122	6,187	\$7,058	3,425	\$9,484
Brazil	768	1,872	362	706	226	1,153	1,272	1,274
Canada	50,486	69,624	32,988	40,400	9,776	13,958	15,123	24,696
China	7,796	3,438	22,873	10,260	14,758	13,905	22,709	22,636
France	396	1,176	—	—	584	821	219	315
Germany, Federal Republic of	5,711	9,873	519	900	13,928	19,212	2,422	4,402
Hong Kong	909	605	5,485	3,960	3,349	2,848	6,875	7,363
India	394	637	594	1,008	32,869	45,562	13,329	15,632
Italy	980	1,710	20	39	12,596	18,181	1,477	3,118
Japan	17,803	40,533	23,721	52,805	28,729	65,522	42,797	78,466
Korea, Republic of	32,282	64,490	29,488	53,864	26,213	47,908	42,397	66,412
Mexico	8,881	19,916	7,497	9,501	12,058	21,346	3,693	6,102
Netherlands	719	1,019	158	116	3,902	5,226	227	354
Singapore	58	64	846	851	2,318	2,838	1,757	2,138
Spain	152	167	20	5	622	726	290	251
Sweden	—	—	22	38	3,432	8,116	779	1,776
Taiwan	10,575	9,849	5,908	6,284	8,745	11,515	11,233	15,668
United Kingdom	878	1,048	82	145	2,417	3,893	870	1,228
Other	473	1,060	641	828	2,057	2,935	4,383	3,214
Total¹	139,624	227,418	131,318	181,833	184,766	292,723	175,275	264,530

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 19
U.S. IMPORTS FOR CONSUMPTION OF COPPER SCRAP, BY
COUNTRY

Country	Unalloyed copper scrap		Copper-alloy scrap		
	Quantity (metric tons)	Value ¹ (thousands)	Gross weight (metric tons)	Copper content* ² (metric tons)	Value ¹ (thousands)
1990	35,904	\$80,976	98,710	71,071	\$192,777
1991:					
Canada	19,587	41,238	54,843	39,487	94,601
Chile	1,008	2,470	37	27	73
Colombia	—	—	2,050	1,476	2,505
Costa Rica	814	853	109	78	91
Dominican Republic	342	304	1,375	990	2,844
El Salvador	275	234	39	28	18
France	1	14	318	229	2,432
Germany	—	—	200	144	624
Guatemala	221	203	288	207	427
Honduras	184	197	503	362	449
Jamaica	563	522	228	164	217
Malaysia	20	24	277	199	916
Mexico	3,257	5,543	27,199	19,583	40,331
Netherlands	79	234	39	28	87
Netherlands Antilles	33	65	573	413	764
Nicaragua	144	184	643	463	591
Panama	393	685	963	693	1,458
Peru	—	—	545	392	998
Phillippines	19	28	235	169	277
Singapore	41	46	202	145	279
Taiwan	36	62	169	122	741
Trinidad and Tobago	170	139	253	182	287
United Kingdom	102	186	811	584	1,977
Venezuela	1,069	1,124	3,760	2,707	6,376
Other	391	592	1,513	1,089	1,989
Total ³	28,751	54,949	97,177	69,967	161,356

*Estimated.

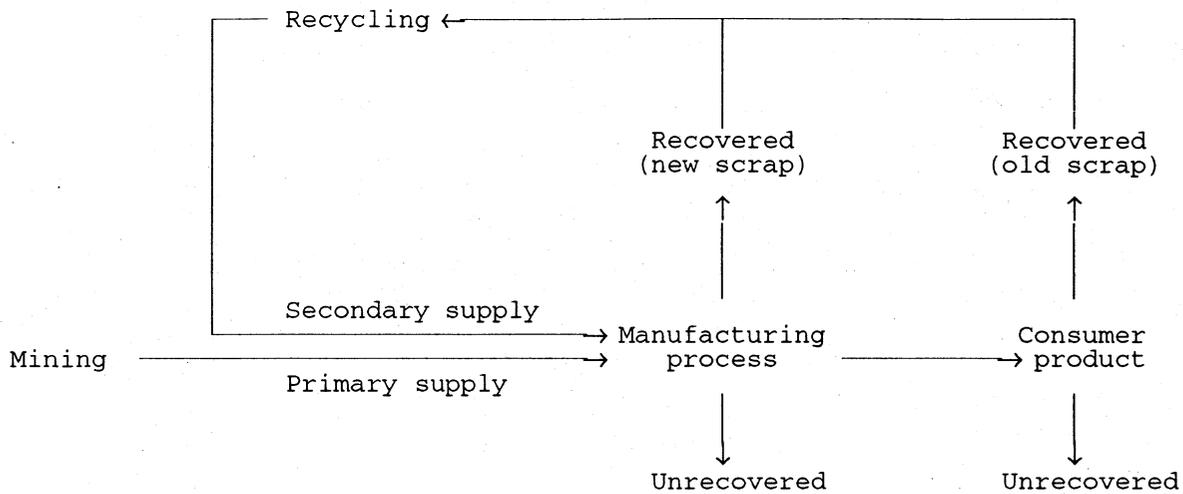
¹C.i.f. value at U.S. port. Values prior to 1989 were customs values.

²Under the Harmonized Tariff System that was implemented Jan. 1989, copper content is no longer available. Content is estimated to be 72% of gross weight.

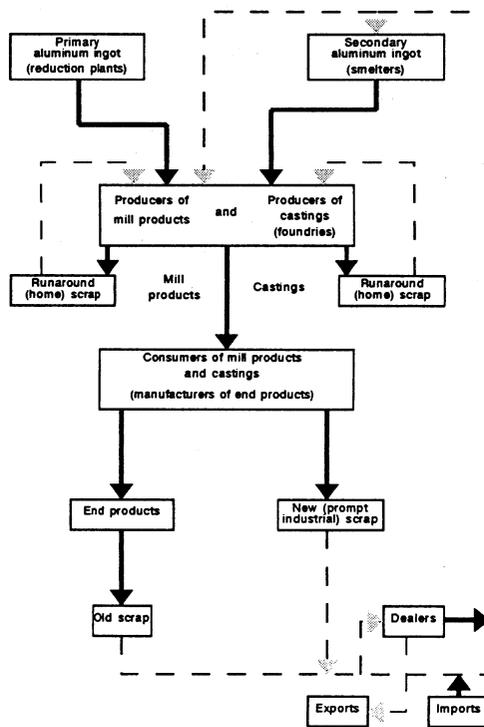
³Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

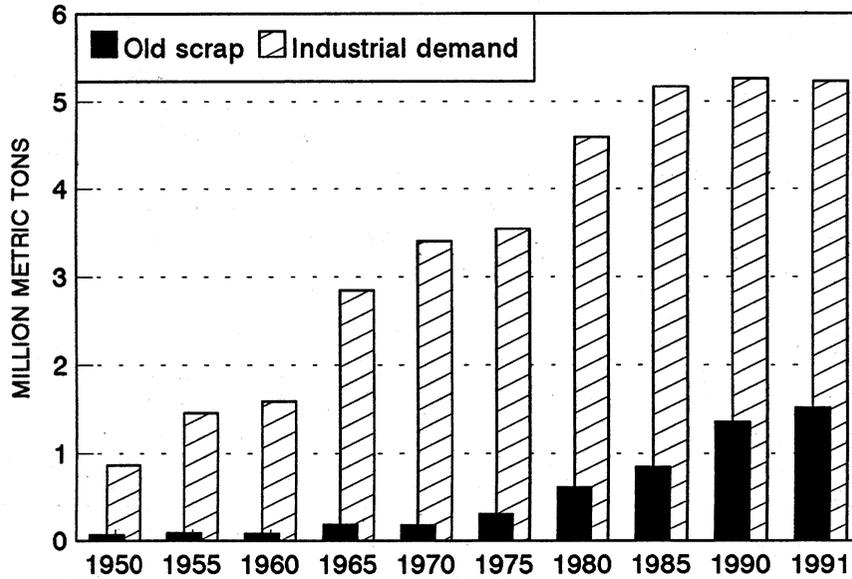
**FIGURE 1
GENERAL RECYCLING MATERIAL INDUSTRY FLOW STRUCTURE**



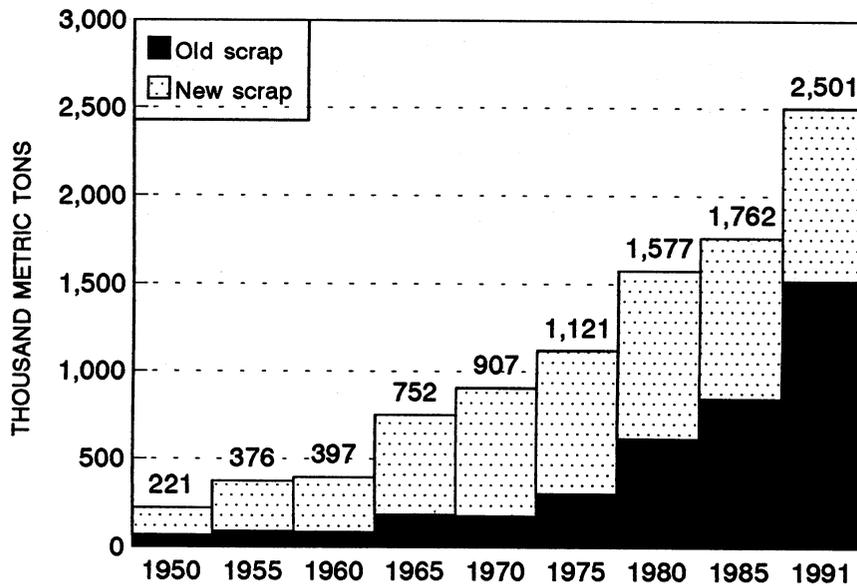
**FIGURE 2
FLOW OF ALUMINUM SCRAP**



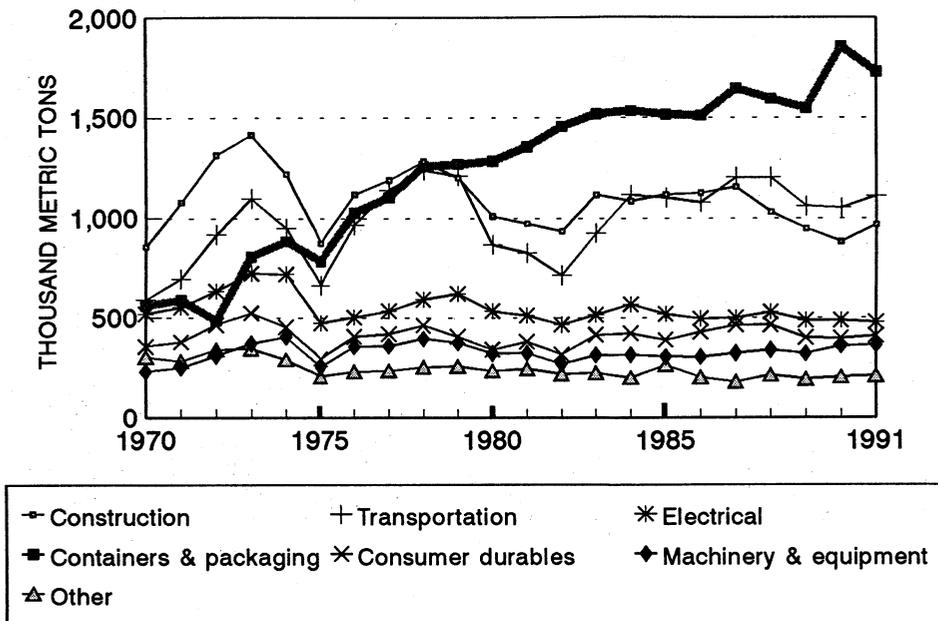
**FIGURE 3
OLD SCRAP COMPONENT OF ALUMINUM DEMAND**



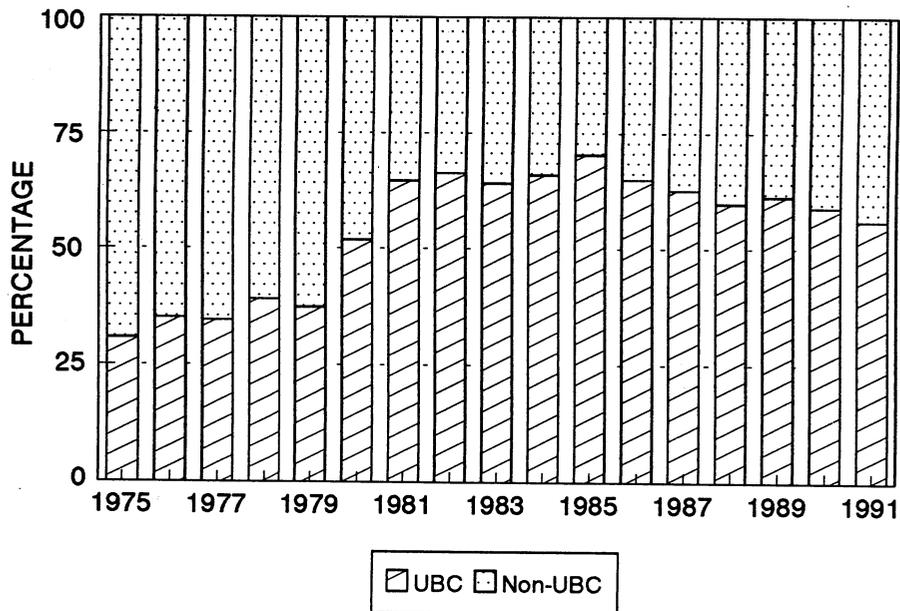
**FIGURE 4
ALUMINUM RECOVERY FROM SCRAP**



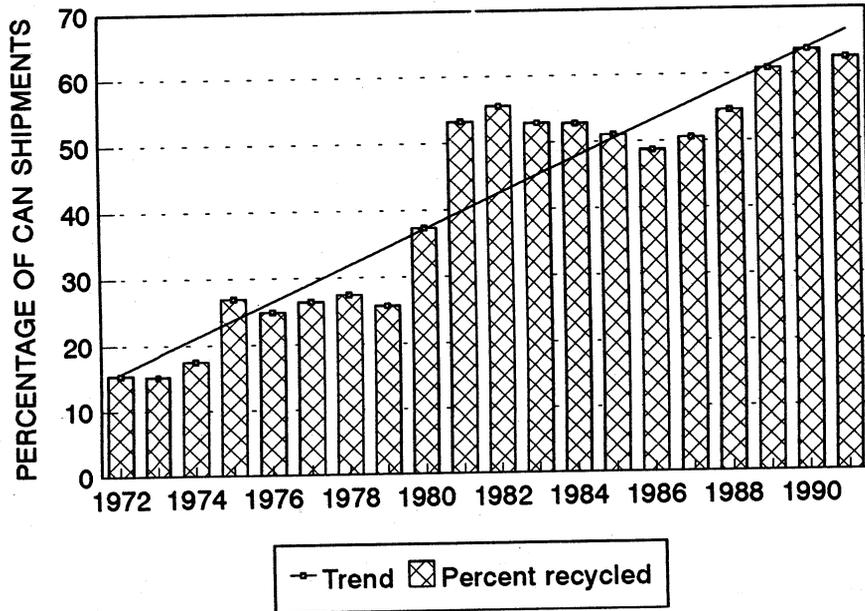
**FIGURE 5
ALUMINUM END-USE PATTERN**



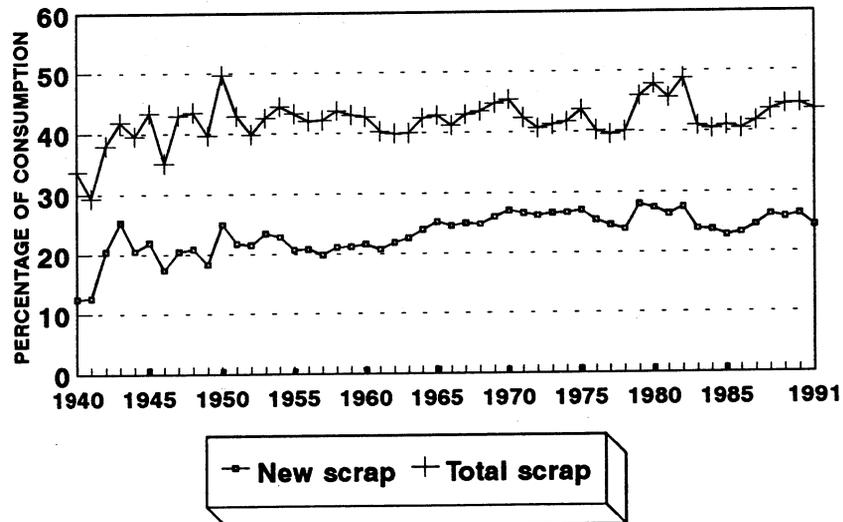
**FIGURE 6
UBC COMPONENT OF OLD SCRAP CONSUMPTION**



**FIGURE 7
U.S. ALUMINUM CAN RECYCLING**

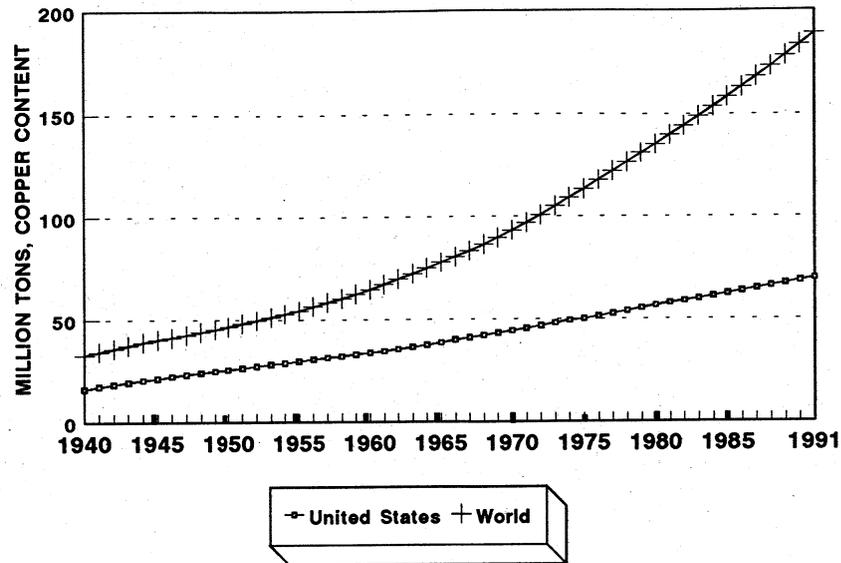


**FIGURE 8
PERCENT TOTAL AND NEW SCRAP IN U.S. COPPER CONSUMPTION**



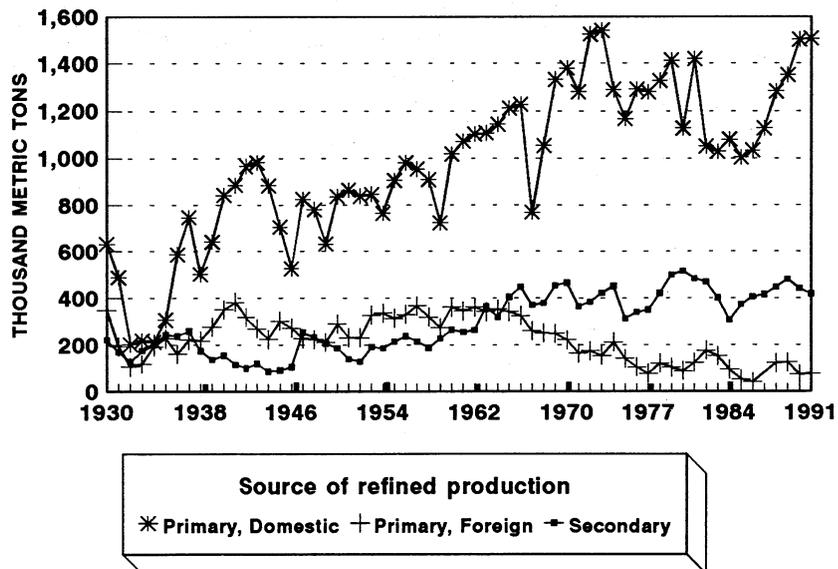
1/Apparent consumption=Refined copper consumption+copper
in all scrap + net refined copper imports + refined stock changes.
Source: U.S. Bureau of Mines, Nov. 1992.

FIGURE 9
U.S. AND WORLD SCRAP RESOURCE POOL OF COPPER MATERIALS IN USE



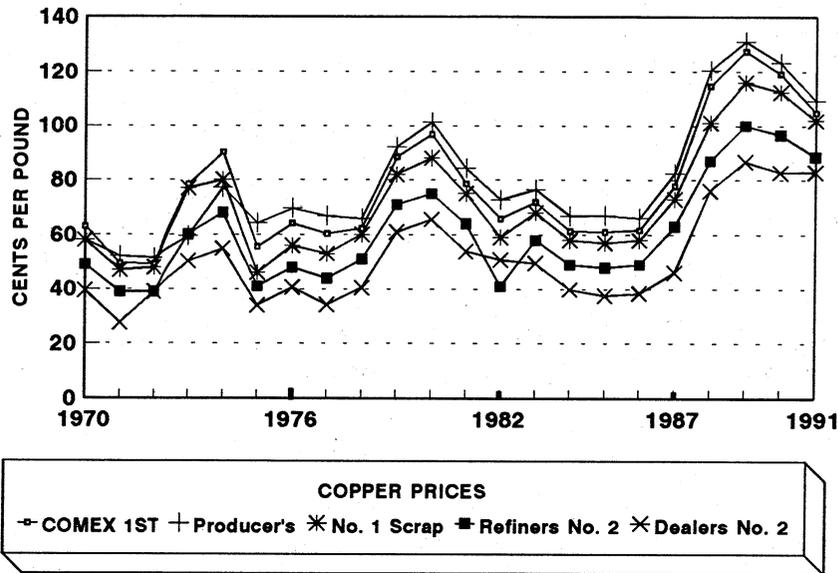
Source: U.S. Bureau of Mines, Oct. 1992

FIGURE 10
U.S. REFINED COPPER PRODUCTION FROM DOMESTIC AND FOREIGN PRIMARY AND SECONDARY SOURCES



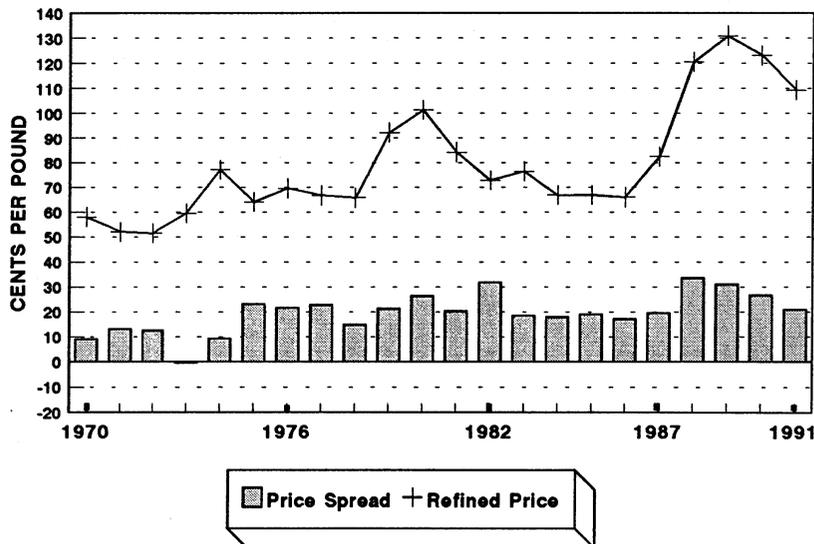
Source: U.S. Bureau of Mines, Nov. 1992

FIGURE 11
COMPARISON OF NO. 1 AND NO. 2 COPPER SCRAP WITH COMEX PRICES AND PRODUCER'S DELIVERED REFINED PRICES



Sources: American Metal Market (scrap) and Metals Week (refined).

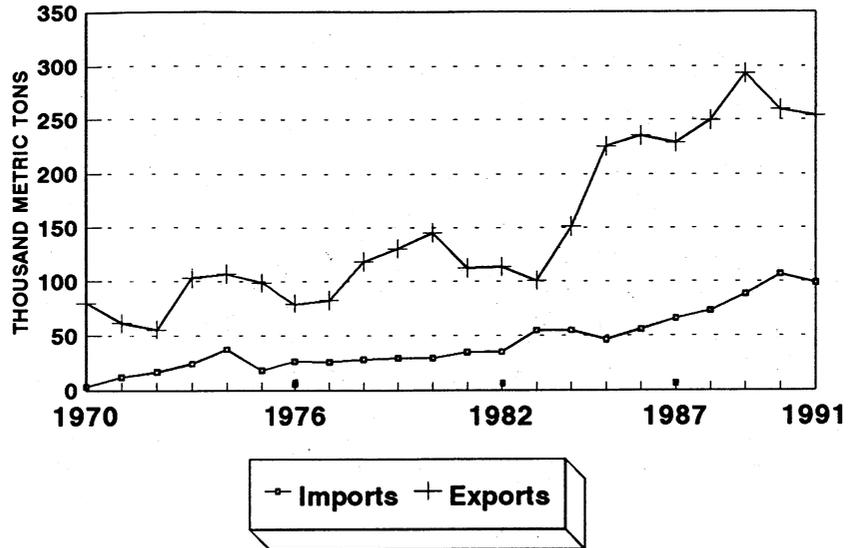
FIGURE 12
PRICE SPREAD TRENDS BETWEEN NO. 2 SCRAP AND U.S. PRODUCERS' REFINED COPPER PRICES



1/ Refiner's buying price for No. 2 scrap.

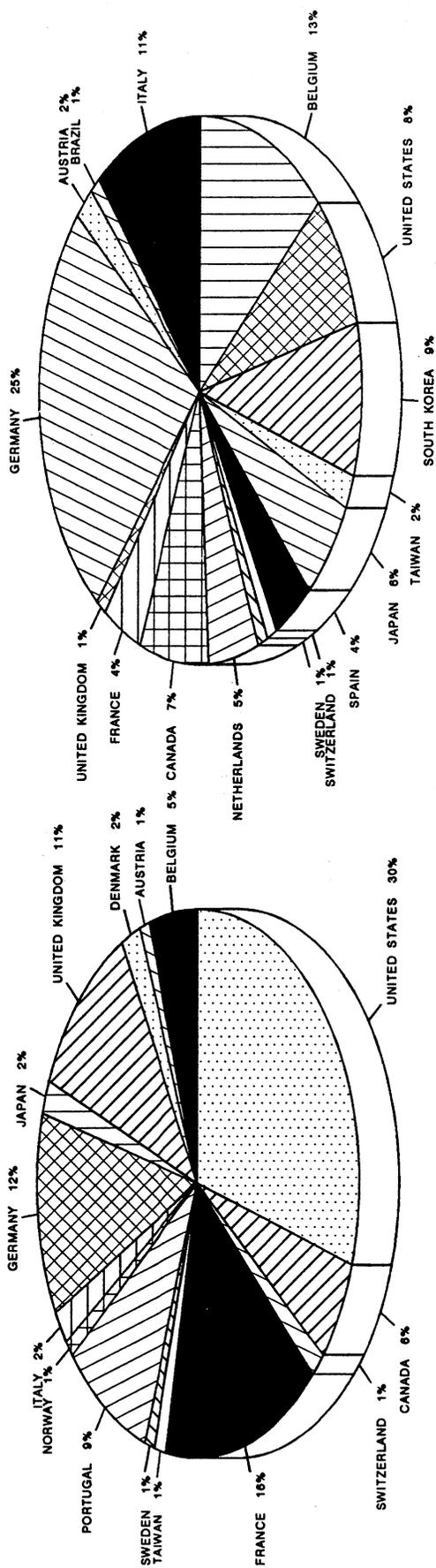
Sources: American Metal Market (scrap) and Metals Week (refined).

FIGURE 13
TRENDS IN U.S. COPPER SCRAP IMPORTS AND EXPORTS



1/ Copper content of copper and copper alloy scrap.
Sources: Bureau of the Census and U.S. Bureau of Mines.

FIGURE 14
 WORLD COPPER SCRAP TRADE IN 1989¹
 (PERCENT OF COUNTRIES SHOWN)



Copper Scrap Exports
 (1.2 million tons, gross weight)

Copper Scrap Imports
 (1.5 million tons, gross weight)

¹/Complete trade data are not available for 1990 and 1991. Eastern Europe, China and India are not included.

Sources: World Bureau of Metal Statistics and Metallgesellschaft.

RHENIUM

By John W. Blossom

Mr. Blossom, a physical scientist and engineer with 44 years of industry and Government experience, has been the commodity specialist for rhenium since 1983. Trade data were prepared by Jo-Ann Sterling, statistical assistant.

Rhenium's two most important uses in the past decade have been in platinum-rhenium catalysts used primarily in producing lead-free, high-octane gasoline and in high-temperature superalloys for jet engine components. Other uses of rhenium, primarily as tungsten-rhenium and molybdenum-rhenium alloys, though smaller in quantity, are more diverse. These include use in thermocouples, heating elements, temperature controls, flashbulbs, vacuum tubes, X-ray tubes and targets, metallic coatings, and electrical contact points. Research by industry continues in rhenium recovery from ore and concentrate and on development of new catalysts and alloys.

In 1991, domestic demand for rhenium metal and other rhenium products was met by domestic recovery, domestic stocks, and imports.

DOMESTIC DATA COVERAGE

Domestic mine production data for rhenium are developed by the U.S. Bureau of Mines from reported molybdenum production at the eight operating porphyry copper-molybdenum-rhenium mines in the United States. (See table 1.)

ANNUAL REVIEW

Rhenium is a byproduct of molybdenite recovered as a byproduct of porphyry copper ore from eight mines in the Western United States. Consumption of rhenium increased about 15% in 1991. Imports for consumption increased 62% in 1991. The major uses for rhenium

during the year were bimetallic platinum-rhenium catalysts and jet engine high-temperature components. The price of rhenium products varied during 1991. The prices on January 1, 1991, for unwrought metal had a range of \$1,610 to \$1,653 per kilogram and ammonium perrhenate had a range of \$1,376 to \$1,453 per kilogram. These prices changed August 1, 1991. Unwrought metal was \$1,213 to \$1,268 per kilogram and ammonium perrhenate was \$1,120 to \$1,157 per kilogram. These prices held through December 31, 1991.

Consumption and Uses

The major uses of rhenium are in petroleum-reforming catalysts and in high-temperature superalloys used in jet engine components. These two uses represent about 30% and 60% of the total demand.

Rhenium is used in petroleum-reforming catalysts for the production of high-octane hydrocarbons, which are used in the production of lead-free gasoline. Bimetallic platinum-rhenium catalysts have replaced many of the monometallic catalysts. Rhenium catalysts tolerate greater amounts of carbon formation and make it possible to operate at lower pressures and higher temperatures, which leads to improved yields and octane ratings.

Catalytic units employing platinum-rhenium catalysts are used in about 80% of total U.S. reforming capacity. Platinum-rhenium catalysts are also used in the production of benzene, toluene, and xylenes, although this use is small

compared with that used in gasoline production.

A significant property of rhenium is its ability to alloy with molybdenum and tungsten. Molybdenum alloys containing approximately 50 weight-percent rhenium have greater ductility and can be fabricated by either warm or cold working. Unlike other molybdenum alloys, this alloy is ductile, even at temperatures down to 196° C, and can be welded. Also, alloys of tungsten with 24 weight-percent rhenium have improved ductility and lower ductile-to-brittle transition temperature than pure tungsten. Rhenium improves the strength properties at high temperatures (1,000° C) of nickel alloys. Some of the uses for these alloys are in thermocouples, temperature controls, heating elements, ionization gauges, mass spectrographs, electron tubes and targets, electrical contacts, metallic coatings, vacuum tubes, crucibles, electromagnets, and semiconductors. These various uses represented only 10% of total demand in 1991.

Foreign Trade

Imports for consumption of ammonium perrhenate came from Chile, the Federal Republic of Germany, Japan, the Netherlands, and Sweden, whereas Chile, the Federal Republic of Germany, and Japan supplied rhenium metal.

World production of rhenium was estimated to be 34 metric tons (75,000 pounds); however, the quantity of rhenium actually recovered is much lower because not all concentrates are processed

to recover the rhenium values. Rhenium was recovered from some byproduct molybdenite concentrates from porphyry copper deposits in Canada, Chile, China, Iran, Peru, the U.S.S.R., and the United States. In addition, the U.S.S.R. also recovered rhenium as a byproduct from the Dzhezkazgan sedimentary copper deposit in Kazakhstan. Rhenium metal and compounds were recovered from molybdenum concentrates in Chile, France, the Federal Republic of Germany, Sweden, the U.S.S.R., the United Kingdom, and the United States. (See tables 2, 3, and 4.)

World Review

The definitions of reserves and reserve base are published in U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification For Minerals," which is reprinted in the introduction of "Mineral Facts and Problems, 1985 Edition" and "Mineral Commodity Summaries, 1990."

Estimated world reserves and reserve base of rhenium appear in table 5. They are contained primarily in molybdenite in porphyry copper deposits. U.S. reserves are concentrated in Arizona and Utah, but are also found in Montana, Nevada, and New Mexico. Canadian reserves are in British Columbia, primarily on Vancouver Island. Chilean reserves are found primarily at four large porphyry copper mines and in lesser deposits in the northern half of the country. In Peru, reserves are concentrated primarily in the Toquepala open pit porphyry copper mine and in about a dozen other deposits in the southern half of the country.

Soviet reserves are in several porphyry copper deposits and one sedimentary copper deposit mainly in the south-central part of the country between the Caspian Sea and northwestern China. Other world reserves are in Europe and in sedimentary copper-cobalt deposits in Zaire, Africa. (See table 5.)

OUTLOOK

In the next 5 years, demand for rhenium metal could increase to about 20

metric tons (45,000 pounds) annually, with propulsion component needs (superalloys) at 60%, petroleum-reforming catalysts at 30%, and the various other uses consuming 10%. This increase in demand may be met by processing a greater amount of concentrates containing rhenium and increasing the rate of recovery into the 90% range. Recycling of rhenium-bearing waste and scrap must be greatly improved. This area will require the development of new technologies.

OTHER SOURCES OF INFORMATION

American Metal Market (daily paper).
Canadian Mining Journal (Canada).
Engineering and Mining Journal.
Mining Engineering.
Mining Journal (London).
Roskill Information Services Ltd.

TABLE 1
SALIENT U.S. RHENIUM STATISTICS

(Kilograms)

	1987	1988	1989	1990	1991
Mine production ¹	9,888	11,929	17,463	17,463	19,210
Consumption ^a	7,031	7,711	8,165	7,711	8,870
Imports (metal)	3,373	3,094	3,785	¹ 5,888	10,847
Imports for consumption of ammonium perrhenate	3,277	2,712	948	¹ 3,002	3,513

^aEstimated. ¹Revised.

¹Calculated rhenium contained in molybdenite concentrates.

TABLE 2
HARMONIZED TARIFF OF U.S. RHENIUM IN 1991

(Kilograms)

Action	HTS No.	Commodity description	Duties import only	
			Most favored nation (MFN)	Non-MFN
Export	2811.19.0000	Other inorganic acids: Other—rhenium, etc.	—	—
Import	2811.19.5050	do.	4.2% ad valorem	25% ad valorem.
Export	2841.90.0000	Salts of peroxometallic acids: Other—rhenium, etc.	—	—
Import	2841.90.2000	Salts of peroxometallic acids: Other—ammonium perrhenate	3.1% ad valorem	25% ad valorem.
Export	8112.91.0000	Rhenium, etc. (metals)—unwrought; waste and scrap; powders	—	—
Import	8112.91.0500	Rhenium, etc. (metals) waste and scrap	Free	Free.
Do.	8112.91.5000	Rhenium, (metals) unwrought; powders	3.7% ad valorem	25% ad valorem.
Export	8112.99.0000	Rhenium, etc. (metals) wrought; etc.	—	—
Import	8112.99.0000	do.	5.5% ad valorem	45% ad valorem.

TABLE 3
U.S. IMPORTS FOR CONSUMPTION OF AMMONIUM PERRHENATE,
BY COUNTRY

Country	1989		1990		1991	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Chile	263	\$151	1,087	\$409	1,381	\$1,132
Germany, Federal Republic of	—	—	149	141	36	41
Japan	—	—	152	130	102	67
Netherlands	—	—	—	—	185	150
Sweden	132	188	1,614	1,447	1,809	1,425
Switzerland	553	610	—	—	—	—
Total	948	949	3,002	2,127	3,513	2,815

^aRevised.

Source: Bureau of the Census.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF RHENIUM METAL,
BY COUNTRY

Country	1989		1990		1991	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Chile	1,683	\$1,582,515	3,791	\$4,332,830	8,571	\$10,634,252
Germany, Federal Republic of	2,097	2,588,163	1,611	1,973,238	1,597	1,889,847
Other	5	25,880	486	558,087	679	792,109
Total	3,785	4,196,558	5,888	6,864,155	10,847	13,316,208

^aRevised.

^bIncludes France, Japan, Sweden, and Switzerland.

Source: Bureau of the Census.

TABLE 5
WORLD RHENIUM RESERVES
AND RESERVE BASE

(Metric tons)

Country	Reserves	Reserve base
Canada	32	1,542
Chile	1,306	2,540
Peru	45	544
U.S.S.R.	594	771
United States	386	4,536
Other countries	91	363
World total	2,454	10,296

SALT

By Dennis S. Kostick

Mr. Kostick, a physical scientist with 13 years U.S. Bureau of Mines experience, has been the commodity specialist for salt since 1980. Domestic survey data were prepared by Ms. Carleen Militello, statistical assistant; and international data tables were prepared by Mr. William Zajac, Chief, International Data Section.

Salt is a universal commodity that is known and used by virtually every person in the world. Sodium chloride, commonly known salt, is an important compound that has a multitude of applications. Most individuals usually only associate salt with highway deicing and food processing; however, the largest end use of salt is as feedstock for chlorine and caustic soda manufacture. These two important inorganic chemicals have a multitude of consumer-related end-use products, such as polyvinyl chloride (PVC) plastic made from chlorine and pulping chemicals manufactured from caustic soda.

DOMESTIC DATA COVERAGE

Domestic production data for salt are developed by the U.S. Bureau of Mines from an annual voluntary survey of U.S. salt-producing sites and of company operations. Of the 73 operations to which a survey request was sent, 71 responded, representing 98% of the total production shown in this report. Production for the nonrespondents was estimated on the basis of their prior response to the 1991 production estimate survey or brine production capabilities for chlor-alkali manufacture.

BACKGROUND

Salt has been an important commodity throughout history. Its presence has determined the location of cities, migration of populations, and routes of trade caravans. One of the earliest accounts of using salt in political-economic societies was traced to 2200 B.C. in China where Emperor Hsia Yu

decreed that Shandong Province would supply the court with salt. The Phoenicians (1200 B.C. to 300 B.C.) were one of the first maritime civilizations to trade salt. Salt became an important universal medium of exchange. The English word "salary" is derived from the Latin term "Salarium argentum," which were the salt rations that Roman soldiers were partially paid for their services. Aside from its use as a medium of monetary exchange, salt has also been used to signify hospitality. The custom of presenting newlyweds wine, bread, and salt shows salt as a life-giving and sustaining substance. In many areas of the world, it is still the custom for the host to offer bread and salt upon entering the home. The custom is also practiced "out of this world"—it has been a tradition that all U.S.S.R. staffed spaceflights carry aloft bread and salt and leave them behind on the orbiting space station as presents for the next visiting crew.

The first production of salt in the United States was in 1614 by the Virginia colonists who evaporated seawater. The practice of extracting salt from subsurface brine was first employed in the United States at Onondaga, NY, in 1788. The first salt "mine" in the United States was dug in 1799 at Saltville, VA. A 6-foot-wide by 200-foot-deep shaft was dug to the top of the salt formation before ground water flooded the workings. The saline water in the shaft provided the feedstock to iron kettles, in which the water was evaporated and the salt recovered. In 1862, the first commercial rock salt mine in North America began operating at Avery Island, LA. Solution mining of salt began in about 1882 and

consisted of drilling a small diameter well down to a salt bed, pumping freshwater down to dissolve the salt, and pumping the resultant brine to the surface for subsequent evaporation. In 1887, the vacuum pan was adopted for salt production, which incorporated a vacuum during evaporation to allow the water to boil from the brine at a lower temperature. This technological achievement reduced fuel consumption below that of direct-heated units.

Definitions, Grades, and Specifications

Technically, salt is a generic term that describes compounds formed by the partial or complete replacement of the hydronium ion of an acid by a metal or metallic radical. Water and salts are the end products from the chemical reaction between acids and bases. Through time, however, "salt" has become synonymous with sodium chloride (common salt) and will be considered synonymous throughout this chapter.

Naturally occurring sodium chloride is mineralogically known as halite. Pure salt contains 39.3% sodium and 60.7% chlorine by weight. Halite deposits usually contain between 1% and 4% impurities, mainly gypsum, shale, dolomite, and quartz. Rock salt is halite that is mined underground by conventional room-and-pillar techniques.

Evaporated salt is the term applied to fine crystals of salt obtained by evaporating brines, either natural or manufactured from solution mining, in large, vacuum-enclosed or open steam-heated kettles. Solar evaporated salt is the product harvested from shallow ponds

after the brine has been exposed to solar and wind evaporation.

The physical characteristics of salt vary with the type of production process. Salt specifications from vacuum pan operations are the same because the process is similar throughout the country. Rock salt, however, can vary in color and composition with locality, and these characteristics influence the specifications of the final product. Some impurities must be removed by chemical treatment or filtration to meet specifications for certain end uses.

There are various standards issued by different organizations that apply to salt. These standards may vary, depending on the intended end use. For example, salt for human consumption requires different specifications than those of salt for deicing highways. (See table 1.)

Products for Trade and Industry

Salt for human consumption is packaged in different sized containers for several specialized purposes. Table salt may contain 0.01% potassium iodide as an additive that provides a source of iodine that is essential to the oxidation processes in the body. Kosher salt, seasalt, condiment salt, and salt tablets are special varieties of salt.

Water conditioning and animal feedstock salt are made into 50-pound pressed blocks. Sulfur, iodine, trace elements, and vitamins are occasionally added to salt blocks to provide missing nutrients not found naturally in the diet of certain livestock. Salt is also compressed into pellets and used for water conditioning.

Geology-Resources

The definitions of reserves and reserve base are published in the U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals."

The oceans are the world's largest resource of salt. Seawater contains 3.5% dissolved solids by weight with sodium chloride representing the major component, approximately 2.5% by

weight. The world's oceans contain about 44×10^{15} short tons of sodium chloride, which is equivalent to 4.5 million cubic miles in volume or a cube measuring 165 miles on edge.

Domestic salt resources are found mainly in four large depositional basins, covering an area totaling about 0.5 million square miles in 18 States. These basins are (1) the gulf coast, which covers part of Florida, Alabama, Mississippi, Arkansas, eastern Texas, and all of Louisiana; (2) the Permian, which is in part of New Mexico, Colorado, Kansas, Oklahoma, and Western Texas; (3) the Salina, covering part of New York, Pennsylvania, West Virginia, Ohio, and Michigan; and (4) the Williston, encompassing part of North and South Dakota, Montana, and Wyoming. The gulf coast and Permian basins extend into Mexico; the Salina and Williston both extend into Canada. The identified salt resources of the United States are estimated at 61×10^{12} tons and are being depleted at the rate of about 39 million tons annually. At the present level of production, the United States has enough salt to mine for more than 1.6 million years. Solar evaporation of coastal seawater would extend this timespan to virtually forever.

Salt can be geologically classified by its occurrence as evaporite deposits and in solutions.

Evaporite Deposits.—Bedded, diapiric flow, and playa salts are the major types of dry salt deposits. Bedded salt deposits were formed by the accumulation of precipitated salts on the seafloor of ancient landlocked marine bodies of water. Extensive and widespread evaporation was essential to form these massive rock salt deposits, some of which measure up to 3,000 feet in thickness.

Salt domes form when vertical or lateral pressures are applied to stratified salt deposits in which low-density salt will flow plastically through the surrounding rocks of higher density. The salt domes of Romania, Germany, and the gulf coast of the United States are examples of diapiric salt flows. The appearance is usually cylindrical with

circular or elliptical diameters. A cap rock of anhydrite is common with overlying layers of gypsum and calcite. Oil, gas, and sulfur are associated with many domes and represent large mineral resources. There are 329 proven salt domes in the gulf coastal province and offshore regions of the United States. Louisiana has 183 domes onshore and offshore; Texas, 83; Mississippi, 61; and Alabama, 2.

Playas are flat, vegetation-free floors of an undrained desert basin that may occasionally be covered by water. Postevaporation minerals such as sodium carbonate, sodium sulfate, sodium chloride, borates, nitrates, phosphates, and potash result from the leaching of the rocks surrounding the basin by water flowing into the playa. Searles Lake in California is a classic example of a salt-bearing playa lake.

Salt in Solution.—Ocean, lake, and ground water are the primary aqueous mediums in which salt is dissolved. Seawater contains many dissolved minerals, the major one being sodium chloride. Other dissolved minerals include various sulfate, magnesium, calcium, and potassium compounds.

Water tends to accumulate on land in topographic depressions created by tectonic uplifts or subsidences of the Earth's upper crust. As mineralized solutions from upland sources drain into these basins, solar evaporation concentrates the salts to form saline lakes. The Aral Sea in the U.S.S.R., Great Salt Lake in Utah, and the Dead Sea between Jordan and Israel are examples of this process.

Ground water is composed of mineralized connate and meteoric water found in permeable sedimentary formations. In some areas, sodium chloride-rich brines migrate to the surface through intersecting fractures and joints in the rock strata to form local salt springs. These springs have attracted animals because they are a source of salt. The springs also indicate where buried salt deposits are located. The salt springs at Saltville, VA, are an example of a

locality that was developed based on an occurrence of salt springs.

Technology

Exploration.—Exploring for new salt deposits is based on examination of various geochemical and geophysical information. Analysis of the underlying strata by core drilling, oil and water well logs, or other techniques is the basis for establishing the size of the deposit. Usually the most favorable areas for mine development will be near the market regions and convenient transportation routes.

The development of mines incorporates strict safety precautions while permitting for the maximum economic recovery of salt. During shaft sinking, water-bearing strata may be encountered, and waterproofing techniques must be employed to prevent mine flooding. At least two access shafts are constructed in room-and-pillar mines to provide adequate safety and ventilation.

Mining.—**Rock Salt.**—Rock salt is mined by the room-and-pillar method, which is similar to that used in coal and trona mining. The salt is drilled, cut, blasted, mucked, crushed, and transported to the surface for processing, which usually involves removing the impurities and screening the material to finer size fractions.

Underground mining practices of bedded rock salt and domal salt formations are similar except for the height differences within the mines of the two types of operations. For example, bedded formations usually are laterally extensive but are vertically restricted. Salt domes are laterally restrictive but are vertically extensive. Many salt domes have depths in excess of 20,000 feet, yet many outcrop at the surface. Most gulf coast salt mining operations are generally less than 1,000 feet below the surface. Working at deeper depths is difficult because of higher temperatures and denser rock.

Solar Evaporation.—Solar evaporation is an effective method of producing solar salt in areas of high evaporation and low precipitation. Along coastal margins in many parts of the world, seawater is collected and allowed to evaporate in specially constructed evaporating ponds. Saline lakewater is also processed using this method. The ponds are separated by levees that isolate the brine during different stages of fractional crystallization.

The initial step concentrates the brine to increase the salinity and allow many calcium, magnesium, and iron compounds to precipitate from solution. The brine is circulated among a network of interconnecting ponds, with salinity increasing with each transfer. The brine is then treated with lime to remove excess calcium sulfate and then pumped to evaporation ponds and then transferred to harvesting ponds to permit the salt to crystallize. After about 85% of the salt is precipitated, the remaining supernatant liquid, called "bitterns," can be drained to adjacent ponds for subsequent extraction of magnesium, potassium, bromine, and sodium compounds. The harvesting pond is flooded again with new brine from the lime pond to repeat the cycle. It takes about 5 years once seawater is first introduced into the system for the completion of the crystallization process. The salt is harvested by special tractors equipped with scrapers and ready for processing.

Solution Mining.—The first reported use of solution mining was about 250 B.C. in China when holes were drilled into deep salt deposits. The brine was brought to the surface by pipes made of bamboo. The brine was evaporated over fires fueled with wood, coal, or natural gas. The basis of current technology began in France about A.D. 858. An injection well is sunk, and pressurized freshwater is introduced to hydraulically fracture the bedded salt. Once communication with the production well is established, the brine is pumped to the surface for treatment.

Roof collapse of the overlying strata and surface subsidence are potential problems associated with solution mining; however, producers have taken precautions to minimize these hazards. One method that was once used was injecting air with the water into the salt caverns. The air formed a protective cover between the water and the top of the cavity that reduced the amount of dissolution of the roof.

Processing.—**Rock Salt.**—About 64% of total rock salt produced and imported is for highway deicing. Crushing and screening to the proper physical size is usually the only processing that road salt undergoes. In many operations, these steps are done underground in the mine to minimize haulage and storage costs. In addition, the extremely fine fraction, which often is unusable, remains underground rather than on the surface, which would represent a waste product to be disposed.

Solar Salt.—After harvesting, the salt crystals are washed with dilute brine to remove residual bitterns and impurities. The salt is transferred to processing facilities where it is washed with saline water, dried for about 8 minutes at approximately 300° F, and screened into fine to coarse sizes, depending on the end use of the salt to be sold. Most operations ship solar salt in bags and in bulk, using barges, truck, and rail transportation.

Mechanical Evaporation.—Salt obtained by dehydrating brine using heat alone or in combination with a vacuum is vacuum pan salt. The vacuum pan process conserves energy by utilizing multiple-effect evaporators connected to vacuum pumps. A saturated salt solution will boil at a higher temperature than pure water. When a vacuum is applied, the brine boils at a lower temperature, enabling the superheated vapor that is generated to act as the heating medium for the next evaporator.

The grainer or open pan process uses open, rectangular pans with steam-heated

immersion coils to evaporate the water in the brine. Rotating rakes scrape the salt precipitate into a sump or up a ramp, depending on the method, and onto conveyors for debrining and drying treatment. The final product is usually flake shaped rather than the typical cubic form. Flake salt is preferred for production of cheese, butter, and baked goods.

The Alberger process is a modified grainer operation that produces cubic salt with some flake salt. The pans are shallow, circular units with external heating units, rather than heating coils. The open pan process cannot be operated successfully in regions with high humidities because the evaporation rate is too slow and more energy is required to evaporate the brine.

Desalination.—The conversion of saline water into freshwater has important municipal, industrial, and agricultural applications. Aside from obtaining pure water, desalination also produces byproduct salt. There are four processes presently employed in water desalination, and each has different cost and energy factors. The processes are distillation, membrane, freezing, and ion exchange. Some salt from these processes is used by the chemical industry. In some regions, salt is returned to the saline water source. Seawater typically contains 3.5% to 4.5% salt, or 35,000 to 45,000 parts per million. The standard for drinking water in the United States is 500 parts per million.

Byproducts and Coproducts

Salt is a coproduct from various seawater and saline lake operations. Depending on the cost of recovery and processing, certain magnesium, potassium, and bromine compounds can be produced from the bitterns. Subterranean brines also contain borax, calcium chloride, sodium carbonate, and sodium sulfate in addition to the above. Certain potash operations in the world also produce salt as a coproduct. When discharged to tailing ponds as a byproduct

of potash mining, salt is often harvested and sold by second parties.

Economic Factors

Energy and labor costs are important factors that affect production costs, and ultimately the selling price, for all types of salt. After the salt is produced, shipping costs become very important when attempting to sell to a customer that is in proximity to other salt producers. Industry sources indicate that within the United States, a 300-mile radius is an effective limit of competition for a producing location before the influence of other competitors is noticed. Some of the major U.S. producers also have foreign subsidiaries that produce salt, which is imported at prices favorable to many consumers because transportation costs are less.

Capital investment and energy costs are important factors that influence the selling price of the type of salt produced. Vacuum pan and open pan processing requires more equipment and energy than solution mining, and consequently, the average value of evaporated salt is considerably higher than that of salt in brine.

Prices.—Each of the four types of salt that are produced have unique production, processing, and packaging factors that determine the selling prices. Generally, salt sold in bulk is less expensive than salt that has been packaged, pelletized, or pressed. Salt in brine is the least expensive salt sold because costs are less. Vacuum pan salt is the most expensive because of the energy costs involved in processing. Table 2 lists the historical values of the different types of salt since 1970. The data are compared with 1991 constant dollars to show the effect of inflation and general economic conditions on the values. (See table 2.)

Tariffs.—The United States historically imports more salt than it exports. In 1991, U.S. salt imports were 3.5 times the level of salt exports. Imports from countries having most-favored-nation

(MFN) status enter duty free. However, salt imported from non-MFN countries have a 26% ad valorem tax imposed.

Operating Factors

Environmental Requirements.—The environmental problems associated with salt mining are few and tend to be localized without major impacts on the environment. A major concern in solution mining is the potential of land subsidence. As the salt is dissolved, some roof collapse may occur, causing sections of the surface to partially or totally fill the cavity. Subsidence is unpredictable, and once the process begins, it must be allowed to finish and reach equilibrium. Another issue pertaining to solution mining is the potential problem of well casing leakage. Any excursion of salt brine could affect ground water supplies, which are protected by various State and Federal water quality regulations. Solar evaporation facilities may substantially disturb coastal marsh areas because of the large extent of the lagoons needed for efficient operation.

Employment.—According to the Bureau of Labor Statistics, 1,522 people were employed in the mining and processing of rock salt in 1991. Of the 12 rock salt facilities surveyed, 773 personnel worked 1.49 million hours underground, 278 people worked 533,810 hours on surface duties, and 471 people worked 913,300 hours in the mills. Total employment in the domestic rock salt industry amounted to 1,758 individuals who worked a total of 3,395,967 hours. Employment data for solar salt, vacuum pan salt, and salt in brine were incomplete or not surveyed by the Bureau of Labor Statistics.

Transportation.—The locations of the salt supplies often are not in proximity of the consumers location, and transportation can become an important cost. Pumping salt brine through pipelines is an economic means of transportation, but cannot be used for dry salt. Large bulk

shipments of dry salt in ocean freighters or river barges are low in cost, but are restricted in points of origin and consumption. River and lake movement of salt in winter is often severely curtailed because of frozen waterways. As salt is packaged, handled, and shipped in smaller units, the costs are increased and are reflected in higher selling prices.

Oceanborne imports of salt have been increasing in some areas of the United States because they are less expensive with respect to transportation costs than what could be purchased from many domestic suppliers using rail transportation. Salt continued to be one of the most heavily traded chemical industry ores in the world, representing about 66% of world seaborne mineral trade.

ANNUAL REVIEW

Issues

The U.S. Environmental Protection Agency (EPA) announced that it plans to set up water quality standards to protect the Nation's rivers, streams, and lakes. A group of 106 toxic pollutants in 22 States and territories was included in the project, especially those compounds that are discharged from various chemical or other industrial facilities. Chlorine-base bleaching agents made from salt have been shown to generate various levels of dioxin (2, 3, 7, 8 tetrachlorodibenzo-p-dioxin or TCDD) and a furan (2, 3, 7, 8, tetrachlorodibenzo furan or TCDF) released by the processes. Dioxins are toxic synthetic compounds that have been identified as carcinogenic to some animals, but studies investigating their effect on humans are controversial and inconclusive. Many pulp mills have begun voluntarily converting from chlorine-base bleaching chemicals to environmentally safe oxygen-base chemicals, such as hydrogen peroxide and sodium chlorate. Although less chlorine would be made, more sodium chlorate, which also uses salt as feedstock, would be produced.

EPA has called for a review of the dioxin risk to humans based on a 1-year

study with new scientific data. EPA's prior assessments may have been too high or too low, but hopefully the new scientific evidence may provide a better evaluation regarding the risk of dioxin contamination.

Production

According to the U.S. Bureau of Mines survey for 1991, 31 companies operated 73 salt-producing plants in 14 States. Ten of the companies and 11 of the plants produced more than 1 million short tons each and accounted for 88% and 53%, respectively, of the U.S. total. Several companies and plants produced more than one type of salt. In 1991, 12 companies (15 operations) produced solar-evaporated salt; 5 companies (17 operations), vacuum pan salt; 10 companies (16 operations), rock salt; and 18 companies (35 operations), salt brine. (See tables 3, 4, 5, and 6 and figure 1.)

The five leading States in terms of total salt sold or used were Louisiana, 37%; Texas, 23%; New York, 13%; and Kansas, 6%. Although Louisiana, New York, and Ohio were major rock salt-producing States, a substantial amount of salt was produced in Alabama, Kansas, Louisiana, New York, Ohio, Texas, Utah, and West Virginia as brine for the chemical industry. (See tables 7 and 8.)

Four companies were involved in a multimillion dollar land and money exchange in Utah in mid-1991. As part of Kennecott's \$270 million expansion near Salt Lake City, the company acquired the 2,600-acre Saltair solar salt facility owned by Morton International Inc. In turn, Morton purchased the Grantsville salt works of North American Salt Co. on the southern shore of the Great Salt Lake with the money it received from the transaction. This provided Morton with greater solar salt production capacity than it had previously. Great Salt Lake Minerals and Chemicals Corp. (GSL), which is a sister-company of North American Salt, planned to expand its solar evaporation ponds on the western shore of the lake with some of North American's profits from the Grantsville sale. Approximately

\$20 million will be spent by GSL to increase potash production from 200,000 tons per year to about 340,000 tons per year.¹

Olin Corp.'s Niagara Falls, NY, chlor-alkali plant that closed in 1990 was dismantled and shipped to El Pasa, Nicaragua. The cells will be used to replace the older cells at the Nicaraguan facility.² New shutdowns of chlor-alkali plants were also announced in 1991. In July, Akzo Chemicals Inc. closed its chlor-alkali unit at LeMoyné, AL. Dow Chemical, which had begun to shut down its Pittsburg, CA, plant in 1990, placed the plant on standby in May 1991; however, by yearend the plant was shut down. Dow reactivated 220,000 tons of chlor-alkali capacity at its Freeport, TX, site to compensate for the closure in California. Hanlin Chemicals—West Virginia, Inc. closed its Moundsville, WV, chlor-alkali plant in midyear.³ LCP Chemicals, a part of the Hanlin Group, Inc., filed for protection under chapter 11 of the Federal Bankruptcy Code in July. The company continued operating its other plants in Georgia, Maine, and North Carolina.

Effective September 1, 1991, Leslie Salt Co. merged with its parent company, Cargill Inc. The Amboy, Napa, Newark, and Redwood City solar salt plants of Leslie were acquired in 1978. All of Leslie's California facilities will be known as Cargill Salt Western Area.⁴ In addition, Cargill implemented a \$4 million expansion project for its salt processing and food products distribution service facility at White Marsh, MD. The operation will include a new 50,000-square-foot salt processing plant.⁵

U.S. salt production accounted for about 20% of total world production. Production and trade of salt increased slightly compared with those of the previous year. World production of all types of salt increased slightly. The depressed market for chlorine and environmental problems associated with emissions of chlorinated compounds may affect the short-term status of the world chlor-alkali industry, which is the largest single consumer of salt.

Consumption and Uses

More than 44.7 million tons of domestic and imported salt was consumed in the United States in 1991, based on the annual survey of the U.S. salt producers. The reported percent distribution of salt by major end use was chemicals, 49%; ice control, 23%; distributors, 11%; food and agricultural, 7%; industrial, 4%; primary water treatment, 1%; and other combined with exports, 5%. Distributors represent a substantial share of salt sales by the salt industry; however, all the salt ultimately is resold to many end users. Some customers have specific uses. For a more complete analysis of end-use markets, specific sectors of distribution in table 9 can be combined, such as agricultural and water conditioning with agricultural and water conditioning distribution, respectively.

The chemical industry is the largest consumer of salt, primarily salt brine. Although most salt brine is captively produced by chemical producers, many chlor-alkali manufacturers purchased brine from independent brine supply companies. In certain cases, brine is captively produced by one chemical company, and any excess brine is sold to neighboring competitors. According to a survey of domestic salt-based chlorine facilities, about 48% of the salt used to manufacture chlorine was captive and 31% was purchased brine. Purchased solar or rock salt comprised 12%, and imported rock, solar, and vacuum pan salt was 9%. (See tables 9 and 10.)

Using Bureau of the Census data, the chlorine and caustic soda industry consumed about 1.97 million tons of salt for feedstock, based on the industry average ratio of 1.75 tons of salt required to produce 1.0 ton of chlorine and 1.1 tons of coproduct sodium hydroxide. Reported consumption of total domestic and imported salt for chlorine manufacture was 20.9 million tons, as noted in table 9. The difference between the calculated and reported quantities was the amount of salt unreported to the U.S. Bureau of Mines from imports or captive brine production of chlor-alkali producers. Production of chlorine gas

and liquid sodium hydroxide, as reported by the Bureau of the Census and The Chlorine Institute, is shown in table 11. (See table 11.)

Table 12 lists the domestic chlorine-producing facilities that used only salt as feedstock. Based on these estimates and using Bureau of the Census chlorine production data, the U.S. salt-based chlorine industry operated at 88% of capacity. According to The Chlorine Institute, the industry operated at an average of 88% of nominal capacity and 93% of effective capacity in 1991. Because these capacities include chlorine produced from nonsalt sources; i.e., from the electrolysis of magnesium chloride and the oxidation of hydrochloric acid, this data may differ from other reported chlorine capacity utilization information. (See table 12.)

Stocks

Total yearend stocks estimated at 2.5 million tons. Most of these inventories were rock salt and solar salt. Because complete inventory data are difficult to determine, many producers do not report this information; therefore, accurate stock data are not available. For discussion purposes, the net increase or decrease in annual inventories is assumed to be the change between salt production and salt sold or used. Many States, municipalities, distributors, and road-deicing contractors stockpiled additional quantities of salt in anticipation of adverse weather conditions.

Markets and Prices

Price quotations are not synonymous with average values reported to the U.S. Bureau of Mines. The quotations do not necessarily represent prices at which transactions actually occurred, nor do they represent bid and asked prices. They are quoted here to serve only as a reference to yearend price levels. Yearend prices were quoted in Chemical Marketing Reporter, as shown in table 13. (See tables 13 and 14.)

Foreign Trade

Under the Harmonized Tariff Schedule nomenclature, imports only have one category known as "Salt (including table and denatuted salt) and pure sodium chloride, whether or not in aqueous solution, seawater." The same classification also applies to exports. The trade tables in this report list the previous and current identification codes for salt.

Based on Bureau of the Census statistics, the United States imported 6.82 million tons in 1991, or about 3.5 times more than the quantity of salt that it exported. Although this would indicate that the United States is import reliant on salt to meet its salt requirements, the majority of imported salt was brought into the country by foreign subsidiaries of major U.S. salt producers. Generally, imported salt can be purchased and delivered to many customers at costs lower than the comparable domestic product because production costs are lower abroad and currency exchange rates are more favorable.

The Journal of Commerce's Port Import/Export Reporting Service (PIERS) reported that 5.23 million tons was imported; however, PIERS data include only ocean freight and does not include salt shipped by rail or truck over the U.S. land borders with Canada and Mexico. Therefore, Census data and PIERS data often are dissimilar. Using PIERS data, Akzo Salt Co., Cargill Inc., Morton International, and North American Salt Co., imported 49% of the total imports. Five companies that manufacture chlorine, which was the single largest domestic salt market, consumed 18% of total imports, which were primarily solar salt. These companies were Atochem North America, Georgia Pacific Corp., LCP Chemical & Plastics Inc., Occidental Chemical Corp., and Weyerhaeuser Co. The salt and chlor-alkali producers imported 67% of total imports; the remainder were to many small direct buyers. Five domestic salt-producing companies exported 65% of the 601,929 tons exported in 1991, according to PIERS. Tables 15 through 18 list the import and export statistics reported by

the Bureau of Census for 1990 and 1991. (See tables 15, 16, 17, and 18.)

World Review

Table 19 lists world salt production statistics for 97 countries based on reported and estimated information. World production increased about 1% in 1991 compared with that of the previous year. Since 1971, world salt production has increased more than 27%, whereas world population has risen 44%, from 3.63 billion to 5.3 billion individuals. (See table 19.)

Industry Structure.—The United States remains the world's leading salt-producing nation, representing about one-fifth of total world production. The structure of the U.S. industry has changed throughout the years. In 1970, there were 50 companies operating 95 plants in the United States. Market competition, energy and labor costs, less expensive imports, and an excess of production capacity reduced the size of the industry to 31 companies and 73 plants by 1991.

Most countries possess some form of salt production capability with production levels set to meet their own domestic demand requirements with additional quantities available for export. Many developing nations tend to develop their agricultural resources first to feed their population. Development of easily extractable mineral resources follows with salt being one of the first commodities to be mined. Some countries, such as the United States, import a substantial amount of salt to meet total demand requirements because of economic factors. (See table 20.)

Capacity.—Each type of salt produced in the world has unique mining, processing, and marketing characteristics that determine the criteria for deriving rated capacities. The data shown in tables 12 and 20 are rated capacities for mines and refineries and salt requirements for salt-based chlorine facilities as of December 31, 1991. Rated capacity is

defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. Capacity data were derived from industry sources, published reports, and estimates based on production trends.

Rock.—Because the majority of rock salt was used for deicing, the operating rate of rock salt facilities fluctuated with the demand for deicing salt, again dependent on the severity of winter weather conditions. During periods of strong demand, production levels often achieve, or exceed in certain situations, the rated capacities. Full mine capacity generally is a function of the hoisting capabilities of the mines. Assuming that the workweek is 5 days (250 workdays per year), two working shifts and one maintenance shift per day, and at least one short-term planned turnaround for the mine and mill per year, table 20 lists the production capacities for domestic rock salt operations.

Solar.—Solar salt, also known as marine and sea salt, is obtained from the solar evaporation of seawater, of landlocked bodies of saline water, and of discharged brines. Because evaporation rates must exceed the precipitation rates, the climatic conditions and geographic locations of solar evaporation facilities are critical to the successful production and harvesting of solar salt. Therefore, rated capacities generally are based on the historical evaporation patterns within a region and vary depending on the location and the surface areas of the evaporation ponds. Only unpredictable seasonal precipitation and market conditions usually affect the production, and market conditions usually affect the production rates of the facilities.

Vacuum Pan.—The mechanical evaporation of salt by the vacuum pan process is dependent on the number and size of the vacuum crystallizers operating in series. Rated capacities are usually easier to establish because of the proven design performance of the equipment.

Brine.—Brine capacities are difficult to derive because they are based on the variabilities of the injection rate of the solvent and the solubility rates of the underground salt bodies. Both determine the quantity of brine produced. In addition, production levels are dependent on the demand for the products that the brine is being used to manufacture. Therefore, individual company brine capacities are not included in table 20. Table 12 lists the quantity, type, and source of the salt required to manufacture chlorine. The amount of brine purchased or used captive is close with the quantity of brine used for chlor-alkali production as noted in table 9.

Canada.—CanadianOxy Chemicals suspended production of chlorine and caustic soda at its Squamish, British Columbia, facility because of the downturn in Canadian chlorine markets. The company had closed a smaller plant at Nanaimo, British Columbia, in 1990. All of CanadianOxy's chlor-alkali production capacity was consolidated at its North Vancouver, British Columbia, operation. Citing similar reasons, Dow Canada closed its Sarnia, Ontario, chlorine and caustic soda facility.

Germany.—Akzo NV announced that it will invest \$10 million to modernize its salt processing plant in Stade, Germany. The project was estimated to take 3 years to complete. The facility has a production capacity of 400,000 tons.

OUTLOOK

The outlook for salt in the 1990's is optimistic. The major producers have diversified into all types of salt across the Nation and have developed reliable import sources in Canada, the Caribbean,

Mexico, and South America. Consolidations and restructuring within the U.S. salt industry have strengthened it into a competitive North American enterprise in the Western Hemisphere. Domestic salt consumption is forecast to grow about 1.3% in 1995. (See table 21 and figure 2.)

¹The Salt Lake Tribune. Four Mineral Firms Strike Golden Deal. June 12, 1991, p. D5

²Chemical Marketing Reporter. Bases and Salts-Chloralkali. Dec. 9, 1991, V. 240, No. 24, p. 30.

³Chlorine Dominating Chloralkali for Now. V. 240, No. 17. Oct. 21, 1991, p. 3.

⁴Industrial Minerals (London). Company News. Cargill Merges Leslie Salt. Oct. 1991, No. 289, p. 57.

⁵Chemical Marketing Reporter. News. Capsule. Cargill Salt Expansion. Apr. 1, 1991, V. 239, No. 13, p. 9.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

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Directory of Companies Producing Salt in the United States, in annual Mineral Industry Surveys.

Salt. Ch. in 1985 Mineral Facts and Problems, quinquennial.

Other Sources

Canadian Minerals Yearbook, Chapter on Salt, annual.

The Chlorine Institute.

Handbook of World Salt Resources. Stanley J. Lefond, 1969, 384 pp.

Salt in Mining Engineering, annual commodity review.

Salt, Industrial Minerals and Rocks, Society of Mining Engineers, 5th ed., v. 2, 1983, pp. 1119-1149.

The Salt Institute.

Sodium Chloride.

Solution Mining Research Institute.

TABLE 1
SPECIFICATIONS APPLYING TO THE SALT INDUSTRY

Type specification	Title	Designation	Jurisdiction
Analysis	Standard Methods for Chemical Analysis of Sodium Chloride	ASTM-E-534-81 ¹	American Society for Testing and Materials.
Food ²	Sodium Chloride	FCC III Food Chemicals Codex, 3d edition	Food and Nutrition Board, National Academy of Sciences.
Highway	Standard Specification for Sodium Chloride	ASTM-D-632-89	American Society for Testing and Materials.
Do.	do.	AASHTO-M-143-86	American Association of State Highway Transportation Officials.
Medical ³	Official Monograph on Sodium Chloride	United States Pharmacopeia XXI, 1985, 21st revision	United States Pharmacopeia Convention, Inc.
Packaging	Salt Packages	ANSI/Z353.1-1983 ⁴	American National Standards Institute Inc.
Do.	Federal Specification-Sacks, Shipping, Paper	UU-S-48F ⁵	General Services Administration.
Reagent	Sodium Chloride	Reagent Chemicals 7th edition, 1986	American Chemical Society.
Soil stabilization	Standard Test Methods for Water-Soluble Chlorides Present as Admixes in Graded Aggregate Road Mixes	ASTM-D-1411-82	American Society for Testing and Materials.
Table salt ²	Proposed Federal Specification-Salt, Table	SS-S-31K	U.S. Army Natick Laboratories.
Water	Federal Specification Commercial Item Description Sodium Chloride, Technical (Water Conditioning Grade)	A-A-694	General Services Administration.
Do.	AWWA Standard for Sodium Chloride	ANSI/AWWA-B200-88	American Water Works Association.

¹E-534-75 is an analytical standard that is necessary for a meaningful salt specification.

²Input regarding food and table salt specification is necessary to maintain quality products in these areas.

³Work has been done with medical salt standards to obtain reasonable specifications.

⁴The ANSI Packaging Standard is a voluntary standard for primary salt containers, secondary containers, and pelletized shipping units.

⁵UU-S-48F gives Federal Sack Specifications. An effort has been made in this area to obtain a reasonable standard.

Source: Salt Institute.

TABLE 2
TIME-VALUE RELATIONSHIPS FOR VARIOUS TYPES OF SALT¹

(Average annual value and 1991 constant dollars,² dollars per short ton)

Year	Salt in brine		Rock salt		Solar salt		Vacuum pan and open pan salt	
	Annual value	Based on constant 1991 dollars	Annual value	Based on constant 1991 dollars	Annual value	Based on constant 1991 dollars	Annual value	Based on constant 1991 dollars
1970	3.67	12.23	2.00	22.00	6.62	22.07	25.51	85.03
1971	3.57	11.29	6.41	20.27	11.02	34.85	26.28	83.10
1972	3.29	9.92	6.19	18.67	8.40	25.33	26.76	80.69
1973	3.57	10.11	6.19	17.54	8.99	25.47	29.65	84.00
1974	3.69	9.62	7.14	18.61	9.30	24.23	34.50	89.00
1975	3.91	9.30	8.94	21.26	14.21	33.79	43.01	102.28
1976	3.80	8.50	7.82	17.49	14.36	32.12	50.73	113.49
1977	3.91	8.18	8.94	18.71	14.21	29.74	52.01	108.86
1978	4.24	8.23	10.10	19.60	14.67	28.46	58.86	114.21
1979	4.51	8.06	10.00	17.86	12.16	21.72	61.64	110.11
1980	6.50	10.61	14.65	23.91	15.65	25.54	76.44	124.73
1981	5.91	8.76	13.76	20.40	18.35	27.21	79.68	118.16
1982	6.21	8.67	13.89	19.39	17.89	24.98	86.72	121.08
1983	5.22	7.00	13.43	18.02	21.47	28.81	87.39	117.25
1984	5.05	6.49	13.78	17.72	19.67	25.29	92.78	119.29
1985	6.14	7.61	15.15	19.21	23.10	28.63	92.66	114.84
1986	5.15	6.22	14.51	17.52	23.76	28.69	91.27	110.20
1987	4.93	5.77	14.34	16.78	25.40	29.72	94.21	110.23
1988	3.58	4.03	14.46	16.28	26.59	29.94	97.71	110.03
1989	5.67	6.12	16.38	17.68	27.88	30.09	92.73	100.09
1990	*4.86	5.04	*16.80	17.41	*31.60	32.75	100.32	103.96
1991	4.94	4.94	17.45	17.45	25.20	25.20	104.10	104.10

¹Revised.

¹Values are based on the average of all salt producers' valuations reported to the U.S. Bureau of Mines of the finished salt in bulk, compressed pellets, and packaged, f.o.b. plant, and includes all processing costs, depreciation of equipment, taxes, and profit.

²From final 1991 implicit price deflators for gross domestic product and not gross national product, which was used previously. In addition, the base year is 1987; previously was 1982.

TABLE 3
SALIENT SALT STATISTICS

(Thousand short tons and thousand dollars)

	1987	1988	1989	1990	1991
United States:					
Production ¹	36,943	39,170	39,278	40,558	40,031
Sold or used by producers ¹	36,493	38,940	38,856	40,693	39,575
Value	\$684,170	\$699,323	\$776,846	\$826,659	\$801,507
Exports	541	884	1,567	2,498	1,959
Value	\$8,217	\$10,858	\$20,211	\$32,944	\$39,875
Imports for consumption	5,716	5,474	6,084	6,580	6,821
Value	\$66,936	\$77,35	\$74,474	\$88,419	\$87,380
Consumption, apparent ²	41,668	43,530	43,373	44,775	44,437
World: Production	*197,010	*201,493	*209,914	*200,989	*202,450

¹Estimated. ²Revised.

¹Excludes Puerto Rico.

²Sold or used plus imports minus exports.

TABLE 4
SALT PRODUCTION IN THE UNITED STATES

(Thousand short tons)

	Vacuum pans and open pans	Solar	Rock	Brine	Total
1987	3,776	3,120	12,230	17,817	36,943
1988	3,824	3,379	12,750	19,218	39,170
1989	3,975	3,140	13,979	18,184	39,278
1990	4,037	3,290	14,079	19,152	40,558
1991	4,028	3,101	12,333	20,569	40,031

¹Data do not add to total shown because of independent rounding

TABLE 5
SALT PRODUCED IN THE UNITED STATES,
BY TYPE AND PRODUCT FORM

(Thousand short tons)

Product form	Vacuum pans and open pans	Solar	Rock	Brine	Total
1990					
Bulk	718	2,259	13,392	19,152	35,521
Compressed pellets	1,118	276	XX	XX	1,394
Packaged	1,844	669	652	XX	3,165
Pressed blocks	357	86	35	XX	478
Total	4,037	3,290	14,079	19,152	40,558
1991					
Bulk	689	2,273	11,693	20,569	35,224
Compressed pellets	1,026	95	XX	XX	1,121
Packaged	1,987	655	607	XX	3,249
Pressed blocks	326	78	33	XX	437
Total	4,028	3,101	12,333	20,569	40,031

XX Not applicable.

TABLE 6
SALT SOLD OR USED¹ IN THE UNITED STATES, BY TYPE AND PRODUCT FORM

(Thousand short tons and thousand dollars)

Product form	Vacuum pans and open pans		Solar		Rock		Brine		Total ²	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1990										
Bulk	717	32,480	1,827	29,319	13,672	205,030	19,537	94,996	35,753	361,825
Compressed pellets	1,116	124,362	246	19,737	NA	XX	XX	XX	1,362	144,099
Packaged:										
Less than 5-pound units	249	NA	—	NA	84	NA	XX	XX	333	XX
More than 5-pound units	1,592	NA	594	NA	599	NA	XX	XX	2,785	XX
Total ²	1,841	211,739	594	35,229	683	36,201	XX	XX	3,118	283,169
Pressed blocks:										
For livestock	166	NA	55	NA	8	NA	XX	XX	229	XX
For water treatment	189	NA	14	NA	28	NA	XX	XX	231	XX
Total ²	355	28,452	69	6,104	36	3,009	XX	XX	460	37,565
Grand total ²	4,029	397,033	2,736	90,389	14,391	244,240	19,537	94,996	40,693	826,659
1991										
Bulk	671	31,856	2,179	35,514	11,540	178,467	20,547	101,475	34,937	347,312
Compressed pellets	1,021	115,333	60	5,453	NA	XX	XX	XX	1,081	120,786
Packaged:										
Less than 5-pound units	318	NA	—	NA	54	NA	XX	XX	372	XX
More than 5-pound units	1,661	NA	537	NA	569	NA	XX	XX	2,767	XX
Total ²	1,979	234,974	537	28,983	623	33,862	XX	XX	3,139	297,819
Pressed blocks:										
For livestock	152	NA	51	NA	6	NA	XX	XX	209	XX
For water treatment	171	NA	11	NA	27	NA	XX	XX	209	XX
Total ²	323	28,133	62	4,691	33	2,764	XX	XX	418	35,588
Grand total ²	3,994	410,296	2,838	74,641	12,196	215,093	20,547	101,475	39,575	801,507

NA Not available. XX Not applicable.

¹As reported at salt production locations. The term "sold or used" indicates that some salt, usually salt brine, is not sold but is used for captive purposes by the plant or company. Because data do not include salt imported, purchased, and/or sold from inventory from regional distribution centers, salt sold or used by type may differ from totals shown in tables 9 and 10, which are derived from company reports.

²Data may not add to totals shown because of independent rounding.

TABLE 7
SALT SOLD OR USED¹ BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand short tons and thousand dollars)

State	1990		1991	
	Quantity	Value	Quantity	Value
Kansas ²	2,390	92,119	2,316	97,713
Louisiana	14,348	120,827	14,595	130,587
New York	5,401	162,900	4,998	173,837
Texas	8,212	75,149	8,935	73,117
Utah	1,171	50,436	1,326	29,959
Other Eastern States ³	6,815	266,312	5,127	233,167
Other Western States ⁴	2,356	58,916	2,278	63,127
Total	40,693	826,659	39,575	801,507
Puerto Rico ⁵	45	1,500	45	1,500

¹Estimated.

²The term "sold or used" indicates that some salt, usually salt brine, is not sold but is used for captive purposes by the plant or company.

³Quantity and value of brine included with "Other Western States."

⁴Includes Alabama, Michigan, Ohio, and West Virginia.

⁵Includes Arizona, California, Kansas (brine only), Nevada, New Mexico, and Oklahoma.

TABLE 8
EVAPORATED SALT SOLD OR USED¹ BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand short tons and thousand dollars)

State	1990		1991	
	Quantity	Value	Quantity	Value
Kansas	1,042	79,001	1,031	83,025
Louisiana	211	22,187	171	18,999
New York	808	74,861	827	79,590
Utah	1,093	47,928	1,257	28,360
Other ²	3,607	263,348	3,546	274,963
Total³	6,764	487,423	6,832	484,937
Puerto Rico ⁵	45	1,500	45	1,500

¹Estimated.

²The term "sold or used" indicates that some salt, usually salt brine, is not sold but is used for captive purposes by the plant or company.

³Includes Arizona, California, Michigan, New Mexico, North Dakota, Ohio, Oklahoma, and Texas.

⁵Data may not add to totals shown because of independent rounding.

TABLE 9
DISTRIBUTION OF DOMESTIC AND IMPORTED¹ SALT BY PRODUCERS IN THE UNITED STATES,
BY END USE AND TYPE

(Thousand short tons)

End use	Standard industrial classification	Vacuum pans and open pans		Solar		Rock		Salt in brine		Grand total ²	
		1990	1991	1990	1991	1990	1991	1990	1991	1990	1991
Chemical:											
Chlor-alkali producers	2812	58	80	402	178	1,264	887	17,458	19,733	19,182	20,878
Other chemical	28 (excludes 2812, 2899)	755	504	158	316	250	344	883	19	2,046	1,183
Total²		813	584	560	495	1,514	1,231	18,341	19,752	21,228	22,062
Food-processing industry:											
Meat packers	201	207	216	99	53	292	139	(³)	—	598	408
Dairy	202	130	121	6	6	4	17	—	1	140	145
Canning	2091, 203	157	146	68	51	91	82	2	2	318	281
Baking	205	144	145	16	2	11	10	—	—	171	157
Grain mill products	204 (excludes 2047)	85	88	1	1	11	14	—	(³)	97	103
Other food processing	206-208, 2047, 2099	199	200	48	52	51	48	(³)	—	298	300
Total²		922	916	238	165	460	310	2	3	1,622	1,394
General industrial:											
Textiles and dyeing	22	144	173	55	52	23	26	4	5	227	256
Metal processing	33, 34, 35, 37	14	16	34	39	298	268	(³)	(³)	346	323
Rubber	2822,30 (excludes 3079)	3	2	8	1	2	3	32	146	45	152
Oil	13, 29	42	31	321	306	120	106	310	168	793	611
Pulp and paper	26	22	22	191	187	63	45	7	7	283	261
Tanning and/or leather	311	9	11	50	30	50	43	—	—	109	84
Other industrial	9621	113	118	79	65	91	101	5	6	288	290
Total²		347	373	738	680	647	592	359	333	2,091	1,978
Agricultural:											
Feed retailers and/or dealers-mixers	434	317	332	242	362	542	515	(³)	(³)	1,101	1,209
Feed manufacturers	2048	74	58	127	95	345	216	—	(³)	546	369
Direct-buying end user	02	17	5	23	8	15	17	—	—	55	30
Total²		407	395	391	465	903	748	(³)	(³)	1,701	1,608
Water treatment:											
Government (Federal, State, local)	2899	28	17	71	93	194	220	4	3	297	333
Commercial or other	2899	13	9	139	86	40	45	7	2	198	142
Total²		41	26	210	180	234	265	11	5	495	476

See footnotes at end of table.

TABLE 9—Continued
DISTRIBUTION OF DOMESTIC AND IMPORTED¹ SALT BY PRODUCERS IN THE UNITED STATES,
BY END USE AND TYPE

(Thousand short tons)

End use	Standard industrial classification	Vacuum pans and open pans		Solar		Rock		Salt in brine		Grand total ²	
		1990	1991	1990	1991	1990	1991	1990	1991	1990	1991
Ice control and/or stabilization:											
Government (Federal, State, local)	9621	4	4	332	217	10,420	9,454	1	2	10,757	9,677
Commercial or other	5159	6	6	32	39	507	596	—	—	545	641
Total²		<u>10</u>	<u>10</u>	<u>364</u>	<u>256</u>	<u>10,927</u>	<u>10,050</u>	<u>1</u>	<u>2</u>	<u>11,302</u>	<u>10,318</u>
Distributors:											
Agricultural distribution	5159	268	310	142	144	209	148	(³)	—	619	602
Grocery wholesalers and/or retailers	514, 54	590	614	196	255	108	120	—	—	894	989
Institutional wholesalers and end users	58, 70	34	32	29	11	33	25	(³)	(³)	96	68
Water-conditioning distribution	7399	286	266	635	519	199	188	3	7	1,123	980
U.S. Government resale	9199	6	6	2	3	1	1	—	—	9	10
Other wholesalers and/or retailers	5251	764	750	352	473	732	769	3	(³)	1,851	1,992
Total²		<u>1,948</u>	<u>1,978</u>	<u>1,356</u>	<u>1,405</u>	<u>1,282</u>	<u>1,251</u>	<u>6</u>	<u>7</u>	<u>4,592</u>	<u>4,641</u>
Other n.e.s. ⁴		<u>162</u>	<u>205</u>	<u>256</u>	<u>413</u>	<u>1,186</u>	<u>1,139</u>	<u>426</u>	<u>491</u>	<u>2,030</u>	<u>2,248</u>
Grand total²		<u>4,650</u>	<u>4,487</u>	<u>4,113</u>	<u>4,059</u>	<u>17,153</u>	<u>15,586</u>	<u>19,146</u>	<u>20,593</u>	<u>45,061</u>	<u>44,725</u>

¹The quantity of imports included in the total for each type of salt is the amount reported by the U.S. salt industry, not the quantity reported by the Bureau of the Census that appears in tables 16, 17, and 18.

²Data may not add to totals shown because of independent rounding. Because data includes salt imported, produced and/or sold from inventory from regional distribution centers, salt sold or used by type may differ from totals shown in tables 3, 6, 7, and 8, which are derived from plant reports at salt production locations. Data may differ from totals shown in table 10 because of changes in inventory and/or incomplete data reporting.

³Less than 1/2 unit.

⁴Includes exports.

TABLE 10
DISTRIBUTION OF DOMESTIC AND IMPORTED EVAPORATED AND ROCK SALT¹ IN THE UNITED STATES,
BY DESTINATION

(Thousand short tons)

Destination	1990				1991			
	Evaporated		Rock	Total	Evaporated		Rock	Total
	Vacuum pans and open pans	Solar			Vacuum pans and open pans	Solar		
Alabama	59	(^o)	288	347	60	(^o)	247	307
Alaska	1	W	(^o)	1	1	17	(^o)	18
Arizona	8	92	28	128	8	87	(^o)	95
Arkansas	39	W	65	104	42	2	66	110
California	172	959	W	1,131	177	838	10	1,025
Colorado	19	123	143	285	18	146	30	194
Connecticut	10	12	243	265	10	14	171	195
Delaware	3	33	11	47	3	29	2	34
District of Columbia	1	8	W	9	1	7	(^o)	8
Florida	95	87	21	203	85	107	51	243
Georgia	258	44	84	386	176	52	67	295
Hawaii	20	4	—	24	2	4	—	6
Idaho	8	88	W	96	8	70	4	82
Illinois	386	139	1,491	2,016	376	113	1,530	2,019
Indiana	195	55	660	910	211	68	763	1,042
Iowa	179	70	481	730	183	75	419	677
Kansas	102	10	687	799	91	19	451	561
Kentucky	56	W	365	421	57	2	404	463
Louisiana	54	W	602	656	53	2	599	654
Maine	116	15	248	379	32	16	225	273
Maryland	65	107	174	346	81	95	124	300
Massachusetts	38	8	482	528	36	19	367	422
Michigan	250	25	1,611	1,886	251	18	1,226	1,495
Minnesota	148	168	518	834	147	174	458	779
Mississippi	26	(^o)	144	170	24	1	195	220
Missouri	139	30	623	792	133	28	784	945
Montana	1	43	W	44	2	50	(^o)	52
Nebraska	90	31	251	372	91	30	162	283
Nevada	1	237	W	238	1	239	W	240
New Hampshire	3	4	101	108	4	6	97	107
New Jersey	123	97	268	488	128	117	236	481
New Mexico	6	114	1	121	7	58	1	66
New York	251	64	2,284	2,599	244	56	1,970	2,270
North Carolina	262	94	41	397	270	83	42	395
North Dakota	21	23	8	52	19	26	15	60
Ohio	377	24	1,419	1,820	377	31	1,528	1,936
Oklahoma	42	W	114	156	34	15	73	122
Oregon	15	53	(^o)	68	18	50	1	69
Pennsylvania	193	123	738	1,054	200	116	977	1,293
Rhode Island	5	4	89	98	6	5	61	72
South Carolina	46	12	9	67	48	11	9	68

See footnotes at end of table.

TABLE 10—Continued
**DISTRIBUTION OF DOMESTIC AND IMPORTED EVAPORATED AND ROCK SALT¹ IN THE UNITED STATES,
 BY DESTINATION**

(Thousand short tons)

Destination	1990				1991			
	Evaporated		Rock	Total	Evaporated		Rock	Total
	Vacuum pans and open pans	Solar			Vacuum pans and open pans	Solar		
South Dakota	39	52	52	143	38	36	38	112
Tennessee	73	1	497	571	75	1	370	446
Texas	180	142	293	615	186	162	259	607
Utah	7	270	W	277	5	243	W	248
Vermont	6	W	188	194	6	1	177	184
Virginia	81	69	161	311	85	37	77	199
Washington	18	230	(²)	248	19	284	1	304
West Virginia	13	W	146	159	14	3	236	253
Wisconsin	236	110	899	1,245	240	94	594	928
Wyoming	(²)	39	(²)	39	(²)	27	1	28
Other ³	115	200	625	940	104	275	468	847
Total⁴	4,651	4,113	17,153	25,917	4,487	4,059	15,586	24,132

W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Each salt type includes domestic and imported quantities. Brine is excluded because brine usually is not shipped out of State.

²Less than 1/2 unit.

³Includes shipments to overseas areas administered by the United States, Puerto Rico, exports, some shipments to unspecified destinations, and shipments to States indicated by symbol W.

⁴Because data include salt imported, purchased and/or sold from inventory from regional distribution centers, evaporated and rock salt distributed by State may differ from totals shown in tables 3, 6, 7, and 8, which are derived from plant reports at salt production locations. Data may differ from totals shown in table 9 because of changes in inventory and/or incomplete data reporting.

TABLE 11
CHLORINE AND SODIUM HYDROXIDE PRODUCTION IN THE UNITED STATES

(Thousand short tons)

	Bureau of the Census		The Chlorine Institute	
	Chlorine gas, 100%	Sodium hydroxide liquid, 100%	Chlorine gas, 100%	Sodium hydroxide liquid, 100%
1986	10,426,072	11,055,060	10,488,664	11,006,709
1987	11,078,189	11,552,686	11,068,581	11,649,078
1988	11,257,478	10,533,288	11,597,282	12,261,834
1989	11,412,592	10,491,951	11,908,810	12,506,814
1990	10,942,857	11,688,182	11,846,896	12,459,157
1991	11,287,783	12,152,063	11,489,896	12,151,285

Sources: Bureau of the Census and The Chlorine Institute.

TABLE 12
U.S. CHLORINE FACILITIES THAT REQUIRE SALT¹

(Thousand short tons)

Company	Location	Annual chlorine production capacity ²	Salt requirements ³	Source of salt requirements
Atochem North America ⁴	Portland, OR	150	263	Imported.
Do.	Tacoma, WA	91	159	Do.
Brunswick Pulp and Paper Co.	Brunswick, GA	36	63	Do.
Dow Chemical USA	Freeport, TX ⁵	2,856	4,998	Captive brine.
Do.	Plaquemine, LA	997	1,745	Do.
E.I. DuPont de Nemours & Co. Inc.	Niagara Falls, NY	84	147	Purchased.
Formosa Plastics Corp, USA	Baton Rouge, LA	200	350	Purchased brine.
Fort Howard Corp.	Green Bay, WI	9	16	Imported.
Do.	Muskogee, OK	9	16	Purchased.
General Electric Co.	Burkville, AL	27	47	Do.
Do.	Mount Vernon, IN	70	123	Do.
Georgia Gulf Corp.	Plaquemine, LA	452	791	Purchased brine.
Georgia Pacific Corp.	Bellingham, WA	91	159	Purchased.
BF Goodrich Group	Calvert City, KY	128	224	Do.
LaRoche Chemicals	Gramercy, LA	219	383	Captive brine.
Hanlin Group	Acme, NC	53	93	Imported.
Do.	Brunswick, GA	108	189	Do.
Do.	Orrington, ME	80	140	Do.
Niachlor (DuPont-Olin)	Niagara Falls, NY	240	420	Purchased brine.
Occidental Chemical Corp.	Convent, LA	296	518	Do.
Do.	Corpus Christi, TX	460	805	Do.
Do.	Deer Park, TX	383	670	Do.
Do.	Delaware City, DE	139	243	Imported.
Do.	LaPorte, TX	515	901	Purchased brine.
Do.	Muscle Shoals, AL	146	255	Purchased.
Do.	Niagara Falls, NY	350	613	Purchased brine.
Do.	Tacoma, WA	237	415	Imported.
Do.	Taft, LA	611	1,069	Purchased brine.
Olin Corp.	Augusta, GA	115	201	Purchased.
Do.	Charleston, TN	256	448	Do.
Do.	McIntosh, AL	365	639	Captive brine.
Pioneer Chlor-Alkali Co.Inc.	Henderson, NV	119	208	Do.
Do.	St. Gabriel, LA	173	303	Do.
PPG Industries, Inc.	Lake Charles, LA	1,150	2,012	Captive and purchased brine.
Do.	Natrium, WV	280	490	Captive brine.
Vulcan Materials Co.	Geismar, LA	246	431	Purchased brine.
Do.	Port Edwards, WI	73	128	Imported.
Do.	Wichita, KS	273	478	Captive brine.
Weyerhaeuser Co.	Longview, WA	130	228	Imported.
Total		12,217	21,381	

¹Includes only those chlorine plants that use salt directly as a feedstock. Does not include plants that produce byproduct chlorine from magnesium chloride and hydrochloric acid oxidation or plants using potassium chloride.

²Based on 365 days per year.

³Based on 1.75 tons of salt required to manufacture 1.0 ton of chlorine with the plant operating at 100% capacity. Salt may be from natural brines, rock, or solar sources, domestic or imported.

⁴Formerly Pennwalt Corp.

⁵An additional 730,000 tons available on standby basis; included in "Total."

NOTE.—The following plants closed in 1991: Alzo at LeMoyné, AL; Hanlin at Moundsville, WV; and RMI at Ashtabula, OH, (metallic sodium).

TABLE 13
SALT YEAREND PRICES

	1990	1991
Salt, evaporated, common:		
80-pound bags, carlots or truckloads:		
North, works, 80 pounds	\$4.02	\$4.02
Bulk, same basis, per ton	60.00-61.20	60.00-61.20
Salt, chemical-grade, same basis:		
North, works, 80 pounds	4.30	4.30
Salt, rock, medium, coarse:		
Same basis, 80 pounds	2.70	2.70
Bulk, same basis, per ton	18.00-25.00	18.00-25.00
Sodium chloride, U.S.P.:		
Granular bags, per pound	.29	.29

Sources: Chemical Marketing Reporter. Current Prices of Chemicals and Related Materials. V. 238, No. 27, Dec. 31, 1990, p. 31; and V. 240, No. 27, Dec. 30, 1991, p. 31.

TABLE 14
AVERAGE VALUES¹ OF SALT, BY PRODUCT FORM AND TYPE

(Dollars per short ton)

Product form	Vacuum pans and open pans	Solar	Rock	Brine
1990				
Bulk	45.30	¹ 16.05	14.99	⁴ 4.86
Compressed pellets	111.44	80.23	XX	XX
Packaged	115.01	59.31	53.00	XX
Average ²	100.32	³ 31.60	¹ 16.80	⁴ 4.86
Pressed blocks	80.15	88.46	83.58	XX
1991				
Bulk	47.48	16.30	15.47	4.94
Compressed pellets	112.96	90.88	XX	XX
Packaged	118.73	53.97	54.35	XX
Average ²	104.10	25.20	17.46	4.94
Pressed blocks	87.10	75.66	83.76	XX

¹Revised. XX Not applicable.

²Net selling value, f.o.b. plant, excluding container costs.

³Salt value data previously reported were an aggregate value per ton of bulk, compressed pellets, and packaged salt. For time series continuity, an average of these three types of product forms is presented, which is based on the aggregated values and quantities of the product form for each type of salt shown in table 6.

TABLE 15
U.S. EXPORTS OF SALT, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1990		1991	
	Quantity	Value	Quantity	Value
Argentina	(¹)	6	(¹)	16
Australia	1	154	2	183
Bahamas, The	2	172	4	181
Bahrain	1	143	—	—
Belize	(¹)	8	—	—
Bolivia	20	197	(¹)	96
Brazil	(¹)	8	(¹)	3
Canada	2,301	25,980	1,420	17,762
Chile	(¹)	3	(¹)	194
Costa Rica	—	—	1	16
Dominican Republic	1	73	(¹)	84
El Salvador	1	352	1	140
France	(¹)	120	6	142
Germany, Federal Republic of	3	34	2	39
Guatemala	—	—	1	118
Honduras	(¹)	8	(¹)	3
Hong Kong	2	256	(¹)	18
Ireland	4	40	11	136
Jamaica	—	—	10	184
Japan	2	81	14	248
Korea, Republic of	2	18	132	1,441
Mexico	101	2,090	298	4,871
Netherlands	—	—	7	77
Netherlands Antilles	1	121	(¹)	67
Panama	(¹)	29	1	89
Saudi Arabia	25	1,535	15	1,771
Sudan	9	290	—	—
Taiwan	2	62	1	92
Trinidad and Tobago	(¹)	3	1	3
United Arab Emirates	1	79	—	—
United Kingdom	1	176	21	704
Venezuela	1	52	—	—
Other	17	854	11	1,197
Total	2,498	32,944	1,959	29,875

¹Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 16
U.S. IMPORTS FOR CONSUMPTION OF SALT

(Thousand short tons and thousand dollars)

Year	Salt in brine ¹		In bags, sacks, barrels, or other packages		Bulk	
	Quantity	Value	Quantity	Value	Quantity	Value
1987	1	67	44	5,122	25,671	61,747
1988	2	125	78	6,682	5,394	70,550
1989	(²)	(²)	(²)	(²)	6,084	74,474
1990	(²)	(²)	(²)	(²)	6,580	88,419
1991	(²)	(²)	(²)	(²)	6,821	87,380

¹Anhydrous salt content.

²Data were adjusted to correct for erroneous notation of shipment from Italy in Aug.

³Included in bulk because categories were merged under HTS code No. 2501000000 in 1989. Before 1989, salt imports were listed under TSUS code Nos. 4209200 for salt in brine, 4209400 for bulk salt, and 4209600 for other salt.

Source: Bureau of the Census.

TABLE 17
U.S. IMPORTS FOR CONSUMPTION OF SALT, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1990		1991	
	Quantity	Value	Quantity	Value
Bahamas, The	874	9,757	714	8,769
Brazil	—	—	44	1,342
Canada	2,102	31,581	3,085	43,042
Chile	847	6,411	354	2,869
France	214	422	363	447
Germany, Federal Republic of:				
Western states	24	931	1	965
Eastern states	31	75	—	—
Ireland	38	436	—	—
Italy	103	1,039	37	416
Korea, Republic of	51	212	180	428
Mexico	1,569	20,146	1,570	18,927
Netherlands	441	12,545	315	7,870
Netherlands Antilles	179	2,795	109	1,778
Spain	13	74	5	25
United Kingdom	58	1,452	(³)	79
Other	36	543	44	423
Total	6,580	88,419	6,821	87,380

³Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 18
U.S. IMPORTS FOR CONSUMPTION OF SALT, BY CUSTOMS DISTRICT

(Thousand short tons and thousand dollars)

Customs district	1990		1991	
	Quantity	Value	Quantity	Value
Anchorage, AK	17	391	38	160
Baltimore, MD	534	6,461	237	3,015
Boston, MA	245	3,159	201	2,624
Buffalo, NY	37	1,179	8	570
Chicago, IL	88	1,507	130	2,768
Charleston, SC	71	1,841	370	5,598
Cleveland, OH	77	1,548	319	5,080
Columbia Snake, OR	464	4,421	467	4,742
Dallas-Fort Worth, TX	(¹)	942	(¹)	63
Detroit, MI	820	11,725	1,231	15,251
Duluth, MN	126	1,754	167	2,047
Great Falls, MT	(¹)	18	(¹)	19
Houston, TX	—	—	(¹)	34
Laredo, TX	(¹)	8	(¹)	2
Los Angeles, CA	67	1,215	169	2,621
Miami, FL	(¹)	38	(¹)	73
Milwaukee, WI	579	8,948	599	9,426
Minneapolis, MN	60	792	21	300
New Orleans, LA	168	2,703	181	2,320
New York, NY	672	5,251	753	4,031
Nogales, AZ	1	22	—	—
Norfolk, VA	203	1,813	85	976
Ogdensburg, NY	63	712	47	835
Pembina, ND	14	322	6	153
Philadelphia, PA	354	4,090	257	3,079
Portland, ME	610	7,180	344	4,602
Providence, RI	143	1,570	54	518
St. Albans, VT	(¹)	8	(¹)	23
St. Louis, MO	(¹)	2	(¹)	3
San Diego, CA	(¹)	35	6	63
San Francisco, CA	(¹)	8	(¹)	4
San Juan, PR	21	327	16	239
Savannah, GA	340	6,842	267	5,287
Seattle, WA	477	5,970	520	6,228
Tampa, FL	173	2,170	187	2,513
Wilmington, NC	157	3,447	140	2,111
Total²	6,580	88,419	6,821	87,380

¹Less than 1/2 unit.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 19
SALT: WORLD PRODUCTION, BY COUNTRY¹

(Thousand short tons)

Country ²	1987	1988	1989	1990	1991 ³
Afghanistan ⁴	11	11	11	11	13
Albania ⁴	83	77	88	94	88
Algeria	257	260	252	248	248
Angola ⁴	66	77	77	77	77
Argentina:					
Rock salt ⁴	1	1	1	1	1
Other salt	1,048	1,373	1,306	1,325	1,325
Australia (marine salt and brine salt)	7,150	7,898	7,792	7,966	8,590
Austria:					
Rock salt	2	1	1	1	1
Evaporated salt	534	455	437	425	420
Other salt	198	282	277	317	305
Bahamas	811	679	946	828	770
Bangladesh ⁴	459	451	457	239	365
Benin ⁴	(⁴)				
Botswana	—	—	—	—	130
Brazil:					
Rock salt	1,047	1,473	1,431	1,139	1,430
Marine salt	3,968	3,329	2,596	4,597	2,755
Bulgaria	101	114	85	183	165
Burkina Faso ⁴	7	7	7	7	7
Burma ⁴	283	271	289	290	290
Cambodia ⁴	45	45	45	45	45
Canada	11,165	11,781	12,188	12,232	12,125
Chile	954	1,149	996	2,022	1,985
China ⁴	19,800	24,250	30,850	22,050	28,110
Colombia:					
Rock salt	226	230	209	230	220
Marine salt	496	521	518	527	525
Costa Rica (marine salt) ⁴	14	30	33	44	44
Cuba	255	221	227	220	220
Czechoslovakia	373	386	379	375	385
Denmark	650	605	666	575	575
Dominican Republic	61	41	33	12	13
Egypt	1,115	1,017	1,281	1,090	990
El Salvador	3	3	6	9	9
Ethiopia: ⁴					
Rock salt	17	17	11	11	11
Marine salt	130	130	110	110	110
France:					
Rock salt	1,627	1,262	1,003	871	880
Brine salt ⁴	1,180	1,200	1,200	1,100	1,100
Marine salt ⁴	1,795	1,820	1,250	1,430	1,325
Salt in solution ⁴	4,040	4,050	4,764	3,706	3,860

See footnotes at end of table.

TABLE 19—Continued
SALT: WORLD PRODUCTION, BY COUNTRY¹

(Thousand short tons)

Country ²	1987	1988	1989	1990	1991 ³
Germany, Federal Republic of:					
Eastern states:					
Rock salt ⁴	3,390	3,300	3,400	2,700	2,205
Marine salt	65	66	66	55	40
Western states: Marketable:					
Rock salt and other	14,178	13,117	12,408	12,426	12,400
Marine salt	666	603	593	568	550
Ghana ⁵	55	55	55	55	55
Greece ⁶	157	209	165	160	160
Guatemala	41	46	70	120	110
Honduras ⁷	35	35	35	35	35
Iceland ⁸	2	2	3	3	3
India:					
Rock salt ⁹	2	4	3	3	3
Marine salt ¹⁰	10,913	10,140	10,580	10,470	10,470
Indonesia ¹¹	660	660	660	660	670
Iran ¹²	784	898	1,091	935	1,100
Iraq ¹³	80	331	330	275	130
Israel	385	398	524	470	440
Italy:					
Rock salt and brine salt	4,072	3,978	3,859	3,964	3,915
Marine salt ¹⁴	630	750	495	495	495
Jamaica	17	17	17	13	15
Japan	1,540	1,502	1,507	1,518	1,520
Jordan ¹⁵	20	20	20	20	20
Kenya (crude salt)	79	104	114	113	110
Korea, North ¹⁶	630	630	630	640	640
Korea, Republic of	732	1,124	915	680	660
Kuwait	39	44	35	33	—
Laos ¹⁷	14	33	9	9	9
Lebanon ¹⁸	3	3	3	3	3
Leeward and Windward Islands ¹⁹	55	55	55	55	55
Libya ²⁰	13	13	13	13	13
Madagascar ²¹	33	33	33	33	33
Mali ²²	5	5	5	5	5
Malta (marine salt) ²³	(²⁴)				
Mauritania ²⁵	6	6	6	6	6
Mauritius ²⁶	7	7	7	7	7
Mexico	7,047	7,483	7,652	7,865	8,372
Mongolia ²⁷	18	18	18	19	19
Morocco	119	146	98	138	143
Mozambique ²⁸	33	41	44	44	44
Namibia	143	166	157	123	108
Nepal ²⁹	2	7	8	8	8
Netherlands	4,386	4,071	4,140	4,027	3,750
Netherlands Antilles ³⁰	390	390	390	390	390
New Zealand	74	50	84	88	88

See footnotes at end of table.

TABLE 19—Continued
SALT: WORLD PRODUCTION, BY COUNTRY¹

(Thousand short tons)

Country ²	1987	1988	1989	1990	1991 ³
Nicaragua*	17	17	17	17	17
Niger*	3	3	3	3	3
Pakistan: ⁴					
Rock salt	295	448	795	841	770
Other	277	293	276	15	15
Panama (refined salt)*	11	10	9	10	11
Peru	490	138	220	220	220
Philippines	492	542	539	541	550
Poland:					
Rock salt	1,360	1,375	1,097	613	550
Other	5,447	5,437	4,051	3,857	3,750
Portugal					
Rock salt	566	591	643	577	580
Marine salt	196	153	165	140	140
Romani	5,947	5,950	7,464	7,165	7,165
Senegal*	83	83	110	100	100
Sierra Leone*	220	220	220	220	220
Somalia*	33	33	33	33	33
South Africa, Republic of	778	748	763	803	733
Spain:					
Rock salt	2,481	2,706	2,300	2,400	2,400
Marine salt and other evaporated salt*	1,041	1,100	1,100	1,100	1,100
Sri Lanka	127	118	166	58	58
Sudan	57	75	100	75	85
Switzerland	430	341	268	280	275
Syria	89	140	152	140	140
Taiwan	110	123	187	91	215
Tanzania	45	22	22	43	43
Thailand:					
Rock salt	4	6	17	131	137
Other*	180	180	180	110	110
Tunisia	468	535	529	443	440
Turkey	1,342	1,526	1,917	1,764	1,874
Uganda*	6	6	6	6	6
U.S.S.R.	16,976	16,314	16,535	16,204	15,430
United Kingdom:					
Rock salt	2,045	1,967	1,305	1,215	660
Brine salt ¹¹	1,713	1,571	1,482	1,478	1,100
Other salt ¹¹	4,048	4,219	4,661	4,399	3,970
United States including Puerto Rico:					
United States:					
Rock salt	11,965	11,797	13,938	14,391	12,196
Solar salt	2,627	2,617	2,754	2,736	2,221
Vacuum pan salt	3,776	3,822	3,967	4,029	3,994
Brine	18,124	19,601	18,198	19,537	20,547
Puerto Rico*	40	40	45	45	45
Venezuela*	550	550	550	474	550

See footnotes at end of table.

TABLE 19—Continued
SALT: WORLD PRODUCTION, BY COUNTRY¹

(Thousand short tons)

Country ²	1987	1988	1989	1990	1991 ³
Vietnam ⁴	250	330	350	375	385
Yemen ⁵	260	245	245	² 243	250
Yugoslavia:					
Rock salt	169	140	¹ 147	¹ 110	110
Brine salt	312	221	² 203	² 225	245
Marine salt	71	64	⁶ 64	⁷ 79	75
Total	¹197,010	²201,493	²209,914	²200,989	202,450

¹Estimated. ²Revised.

³Table includes data available through June 15, 1992.

⁴Salt is produced in many other countries, but quantities are relatively insignificant and reliable production data are not available. Some salt brine production data for manufacture of chlorine, caustic soda, and soda ash are not reported because of incomplete data reporting by many countries.

⁵Reported figure.

⁶Year ending June 30 of that stated.

⁷Less than 1/2 unit.

⁸Brine salt production as reported by the Burmese Government in thousand short tons, was as follows: 1987—64 (revised) 1988—66 (revised); 1989—66; 1990—55 (revised); and 1991—46 (reported).

⁹Year beginning Mar. 21 of that stated.

¹⁰Does not include production from Sardinia and Sicily, estimated at 200,000 metric tons annually.

¹¹Year ending July 15 of that stated.

¹²Great Britain only.

¹³Data captioned "Brine salt" for the United Kingdom are the quantities of salt obtained from the evaporation of brines; that captioned "Other salt" are the salt content of brines used for purposes other than production of salt.

TABLE 20
U.S. SALT ANNUAL PRODUCTION CAPACITIES IN 1991

(Thousand short tons)

Company	Plant	Type of salt			Total
		Rock	Solar	Vacuum pan	
Akzo Salt Inc.	Avery Island, LA	2,400	—	—	2,400
Do.	Manistee, MI	—	—	325	325
Do.	St. Clair, MI	—	—	395	395
Do.	Retsof, NY	4,000	—	—	4,000
Do.	Watkins Glen, NY	—	—	335	335
Do.	Akron, OH	—	—	300	300
Do.	Cleveland, OH	2,300	—	—	2,300
Do.	Lakepoint, UT ¹	—	200	—	200
Cargill Inc.	Amboy, CA ²	—	75	—	75
Do.	Napa, CA ^{2 3}	—	275	—	275
Do.	Newark, CA ²	—	750	150	900
Do.	Redwood City, CA ²	—	350	—	350
Do.	Hutchinson, KS	—	—	325	325
Do.	Breaux Bridge, LA	—	—	150	150
Do.	Lansing, NY	1,300	—	—	1,300
Do.	Watkins Glen, NY	—	—	300	300
Do.	Freedom, OK	—	200	—	200
Great Salt Lake Minerals and Chemicals Corp.	Ogden, UT	—	1,500	—	1,500
Huck Salt Co.	Fallon, NV	15	—	—	15
Hutchinson Salt Co. ⁴	Hutchinson, KS	600	—	—	600
Independent Salt Co.	Kanopolis, KS	500	—	—	500
Lyons Salt Co. ⁵	Lyons, KS	250	—	—	250
Moab Salt Inc.	Moab, UT	—	200	—	200
Morton International Inc.	Glendale, AZ	—	150	—	150
Do.	Hutchinson, KS	—	—	350	350
Do.	Weeks, LA	1,700	—	125	1,825
Do.	Manistee, MI	—	—	360	360
Do.	Silver Springs, NY	—	—	275	275
Do.	Fairport, OH	2,000	—	—	2,000
Do.	Rittman, OH	—	—	600	600
Do.	Grand Saline, TX	400	—	100	500
Do.	Salt Lake City, UT	—	200	—	200
New Mexico Salt and Mineral Corp.	Carlsbad, NM	—	30	—	30
North American Salt Co. ⁶	Lyons, KS	—	—	300	300
Do.	Hutchinson, KS	—	—	225	225
Do.	Baldwin, LA	1,700	—	—	1,700
Do.	Grantsville, UT	—	300	—	300
Pacific Salt and Chemical Co.	Trona, CA	—	200	—	200
Redmond Clay and Salt Co.Inc.	Redmond, UT	80	—	—	80
Salt Products Co.	Milligan, CA	—	10	—	10
United Salt Corp.	Carlsbad, NM	—	250	—	250
Do.	Hockley, TX	150	—	—	150
Do.	Houston, TX	—	—	125	125
Western Salt Co.	Chula Vista, CA	—	125	—	125
Williams Brine Service	Carlsbad, NM	—	10	—	10
Total		17,395	4,825	4,740	26,960

See footnotes at end of table.

TABLE 20—Continued
U.S. SALT ANNUAL PRODUCTION CAPACITIES IN 1991

(Thousand short tons)

Company	Plant	Type of salt			Total
		Rock	Solar	Vacuum pan	
Brine producers ⁷	Various locations	—	—	—	20,569
Grand total		<u>17,395</u>	<u>4,825</u>	<u>4,740</u>	<u>47,529</u>

¹Operated as Akzo Salt of Utah Inc., a wholly owned subsidiary of Akzo.

²Formerly operated by Leslie Salt Co. As of Sept. 1, 1991, Leslie's plants merged with Cargill to become Cargill Salt Western Area.

³Closed Dec. 1990. Sold from inventory during 1991.

⁴Formerly Carey Salt Co's., rock salt operation. The vacuum pan salt operation is owned by North American Salt Co. effective Dec. 1990.

⁵Formerly American Salt Co's., rock salt operation. The vacuum pan operation is owned by North American Salt Co. effective Dec. 1990.

⁶Company formed in 1990 by the acquisition of the Kansas vacuum pan salt operations of American Salt Co. and Carey Salt Co., and the rock salt and solar salt facilities of Domtar Industries Inc., in Louisiana and Utah, respectively.

⁷Includes brine for sale and for captive use. Brine production capacity is assumed to be equal to the quantity of annual brine production, as shown in tables 4 and 5. Brine producers include those chloralkali manufacturers that purchase brine or use captive brine, as listed in table 12.

TABLE 21
U.S. SALT SUPPLY-DEMAND RELATIONSHIPS

(Thousand short tons)

	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
WORLD PRODUCTION										
Production:										
United States	44,010	44,298	46,423	41,710	43,801	42,922	42,878	46,317	41,483	38,899
Rest of world*	117,340	126,185	136,813	136,497	133,304	130,185	142,584	144,790	144,673	150,054
Total*	161,350	170,483	183,236	178,207	177,105	173,107	185,462	191,107	186,156	188,953
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY										
Components of U.S. supply										
Domestic sources	44,010	44,298	46,423	41,710	43,801	42,922	42,878	46,317	41,483	38,899
Sold or used ¹	45,022	43,910	46,536	41,030	44,191	43,412	42,869	45,793	40,352	38,907
Imports	3,463	3,207	3,358	3,215	4,352	4,529	5,380	5,275	5,263	4,319
Industry stocks, Jan. 1 ²	—	—	—	—	—	—	—	—	—	—
Total U.S. supply	48,485	47,117	49,894	44,245	48,543	47,941	48,249	51,068	45,615	43,226
Distribution of U.S. supply										
Industry stocks, Dec. 31 ²	—	—	—	—	—	—	—	—	—	—
Exports	869	609	521	1,332	1,007	1,008	776	697	831	1,046
Industrial demand	47,616	46,508	49,373	42,913	47,536	46,933	47,473	50,371	44,784	42,180
U.S. DEMAND PATTERN³										
Agriculture	1,963	2,083	1,983	1,862	1,925	1,825	1,851	1,917	1,834	1,788
Alkalies and chlorine	26,725	28,344	28,600	24,154	25,970	25,111	24,511	26,962	24,744	22,722
Deicing	11,248	7,306	9,111	8,840	10,193	10,416	10,690	11,138	7,476	8,257
Food products	2,953	2,951	2,970	2,734	2,766	2,756	2,815	2,526	2,368	2,203
Metal production	227	228	252	265	342	351	346	356	272	294
Other chemicals	1,063	1,402	1,734	1,021	1,158	1,122	1,159	1,222	1,020	1,133
Paper products	201	209	165	172	213	222	221	194	230	247
Petroleum	202	215	242	261	312	361	451	550	709	837
Textiles and dyeing	207	201	205	180	204	196	182	188	177	220
Water treatment	842	816	1,029	905	720	812	890	958	865	1,006
Other ⁴	2,833	2,917	3,328	3,254	3,655	3,620	3,504	3,528	3,275	3,754
Undistributed ⁵	-848	-164	-246	-735	78	141	853	832	1,814	-281
Total U.S. primary demand	47,616	46,508	49,373	42,913	47,536	46,933	47,473	50,371	44,784	42,180
VALUES⁶										
Average annual value (dollars per ton):										
Salt in brine	3.29	3.57	3.69	3.91	3.80	3.91	4.24	4.51	6.50	5.91
Rock salt	6.19	6.19	7.14	8.94	7.82	8.94	10.10	10.00	14.65	13.76
Solar salt	8.40	8.99	9.30	14.21	14.36	14.21	14.67	12.16	15.65	18.35
Vacuum pan and open pan salt	26.76	29.65	34.50	43.01	50.73	52.01	58.86	61.64	76.44	79.68

See footnotes at end of table.

TABLE 21—Continued
U.S. SALT SUPPLY-DEMAND RELATIONSHIPS

(Thousand short tons)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
WORLD PRODUCTION										
Production:										
United States	37,665	32,973	39,181	39,217	37,282	36,943	39,170	39,278	40,558	40,031
Rest of world ^a	143,406	142,126	151,077	151,412	155,330	¹ 160,067	¹ 162,323	¹ 170,636	¹ 160,431	¹ 162,419
Total ^a	181,071	175,099	190,258	190,629	192,612	¹ 197,010	² 201,493	² 209,914	² 200,989	² 202,450
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY										
Components of U.S. supply										
Domestic sources	37,665	32,973	39,181	39,217	37,282	36,943	39,170	39,278	40,558	40,031
Sold or used ¹	37,894	34,573	39,225	40,067	36,663	36,493	38,940	38,856	40,693	39,575
Imports	5,451	5,997	7,545	6,207	6,665	5,716	5,474	6,084	6,580	6,821
Industry stocks, Jan. 1 ²	—	—	—	—	—	—	—	—	—	—
Total U.S. supply	43,345	40,570	46,770	46,274	43,328	42,209	44,414	44,940	47,273	46,396
Distribution of U.S. supply										
Industry stocks, Dec. 31 ²	—	—	—	—	—	—	—	—	—	—
Exports	1,001	517	820	904	1,165	541	884	1,567	2,498	1,959
Industrial demand	42,344	40,053	45,950	45,370	42,163	41,668	43,530	43,373	44,775	44,437
U.S. DEMAND PATTERN³										
Agriculture	1,566	1,605	1,722	1,718	1,651	1,755	1,827	1,925	2,320	2,210
Alkalies and chlorine	19,151	20,240	20,142	20,436	18,983	17,955	19,968	18,780	19,182	20,878
Deicing	10,839	6,889	10,721	11,180	10,541	9,878	11,125	11,461	11,302	10,316
Food products	2,352	2,292	2,175	2,109	2,171	2,328	2,287	2,374	2,516	2,383
Metal production	294	242	326	382	304	311	374	400	346	323
Other chemicals	865	952	1,258	768	818	760	766	1,177	2,046	1,183
Paper products	209	274	337	311	307	387	376	373	283	261
Petroleum	1,035	918	870	965	627	597	819	720	793	611
Textiles and dyeing	165	171	191	186	226	237	229	234	227	256
Water treatment	806	795	1,948	1,441	1,553	1,455	1,514	1,487	1,618	1,475
Other ⁴	3,954	4,049	4,188	3,382	3,063	4,074	3,805	4,875	4,428	4,829
Undistributed ⁵	1,108	1,626	2,072	2,492	1,919	1,931	440	-433	-286	-288
Total U.S. primary demand	42,344	40,053	45,950	45,370	42,163	41,668	43,530	43,373	44,775	44,437
VALUES⁶										
Average annual value (dollars per ton):										
Salt in brine	6.21	5.22	5.05	6.14	5.15	4.93	3.58	5.67	⁴ 4.86	4.94
Rock salt	13.89	13.43	13.78	15.15	14.51	14.34	14.46	16.38	¹ 16.80	17.45
Solar salt	17.89	21.47	19.67	23.10	23.76	25.40	26.59	27.88	³ 31.60	25.20
Vacuum pan and open pan salt	86.72	87.39	92.78	92.66	91.27	94.21	97.71	92.73	100.32	104.10

^aEstimated. ^bPreliminary. ^cRevised.

¹Represents that amount sold or used captively within the industry, from the quantity produced and any sold from inventory. Accurate data on beginning and yearend inventories of salt are unavailable and often are underreported because of additional storage underground at mines, warehouses, terminals, etc. However, about 2.5 million tons is estimated to be stored annually nationwide.

²The total quantities of salt in inventory are underreported and are excluded in determining the supply-demand balance relationship for salt. However, the difference between production and sold or used is assumed to be because of changes in inventory.

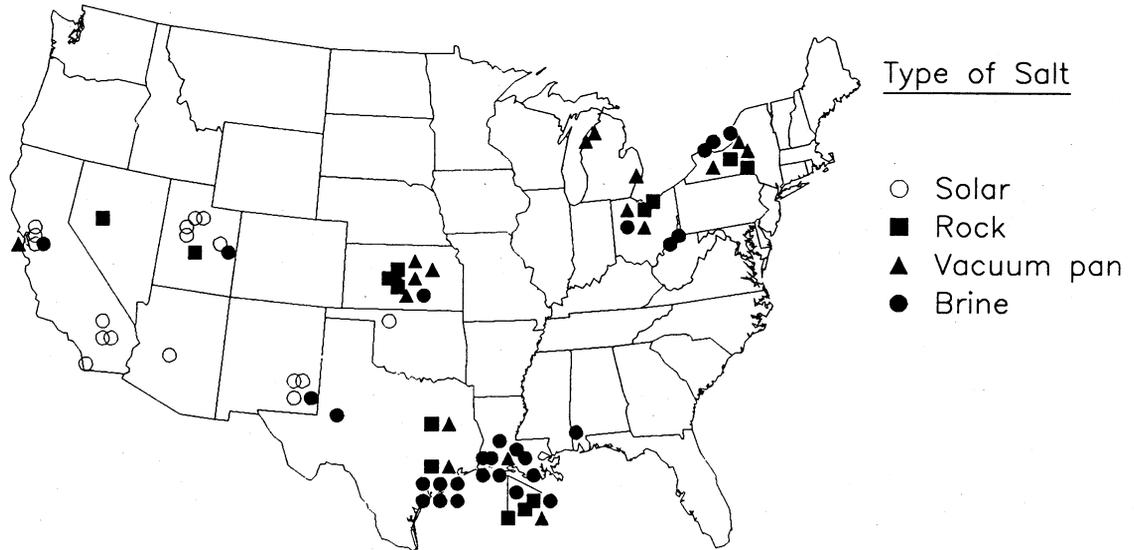
³Includes imports for consumption.

⁴Includes salt used in rubber; tanning; other industrial; institutional wholesalers and/or retailers; U.S. Government resale; other wholesalers; some exports for consumption in overseas territories administered by the United States; and other various minor uses.

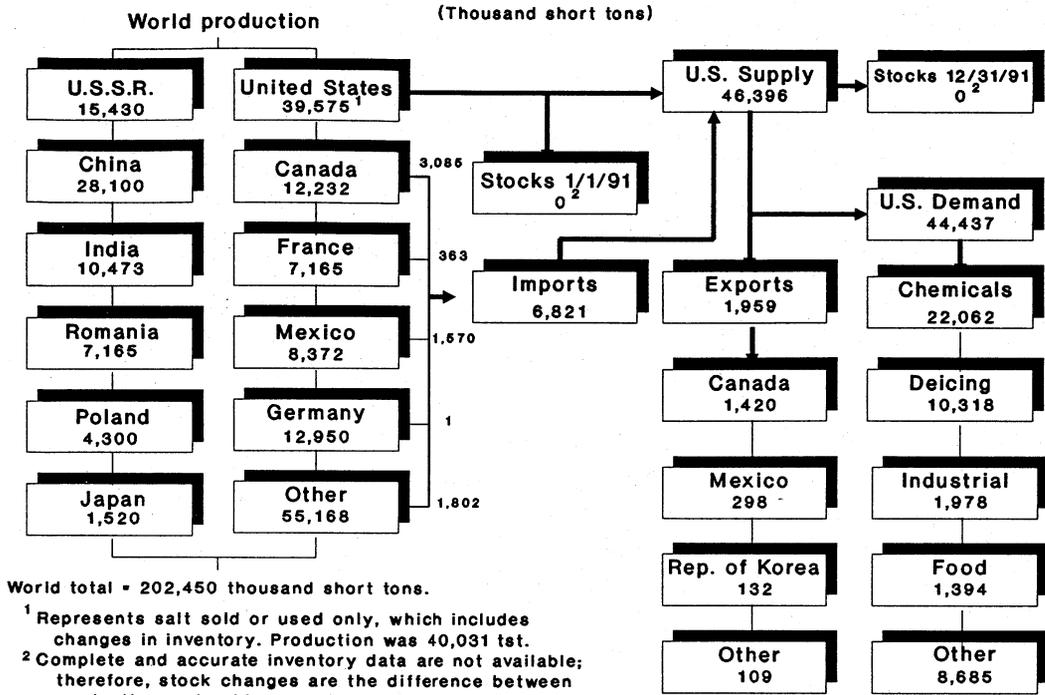
⁵Represents the difference between the quantity reported to the U.S. Bureau of Mines and total U.S. primary demand. The amount of discrepancy is attributed to variances in inventory and import statistics.

⁶Values are based on the average of all salt producers' valuations reported for bulk, f.o.b. plant, and includes all processing costs, depreciation of equipment, taxes, and profit.

FIGURE 1
U.S. SALT PRODUCTION LOCATIONS, 1991



**FIGURE 2
SALT SUPPLY-DEMAND RELATIONSHIPS, 1991**



Source: U.S. Bureau of Mines.

CONSTRUCTION SAND AND GRAVEL

By Valentin V. Tepordei

Mr. Tepordei, a geological engineer with more than 20 years of industry experience, has been the construction sand and gravel commodity specialist with the U.S. Bureau of Mines since 1979. Domestic survey data were prepared by the construction sand and gravel survey staff of the Branch of Data Collection and Coordination.

Construction sand and gravel is one of the most accessible natural resources and a major basic raw material used mostly by the construction industries. Despite the relative low value of its basic products, the construction sand and gravel industry is a major contributor to and an indicator of the economic well-being of the Nation.

A total of 780 million short tons of construction sand and gravel was estimated to have been produced in the United States in 1991, a 14.3% decrease compared with the total production of 1990. This tonnage represents the lowest production level since 1986, indicating a significant decline in the demand for construction aggregates in the United States in 1991. (See table 1.)

Foreign trade of construction sand and gravel remained relatively minor. Exports of construction sand decreased 6.2% to 439,000 tons, while value increased 9.4% to \$13 million. Exports of construction gravel declined 17.8% to 700,000 tons compared with those of 1989, and value declined 21.6% to \$6 million, again compared with those of 1989, because no information on exports of gravel was available for 1990. Imports decreased 15.9% to 1.5 million tons, while the value decreased 27.4% to \$16.6 million. Domestic apparent consumption of construction sand and gravel was 781 million tons.

The removal of nonasbestiform Anthophyllite, Tremolite, and Actinolite (AT&A) from the scope of the present Occupational Safety and Health Administration (OSHA) standards for regulating occupational exposure to asbestos in general industries eliminates a major area of concern of the construction

aggregates industries. The implementation of the provisions of the amended Federal Water Pollution Control Act of 1977, the Clean Water Act, Section 404, dealing with "wetlands" and the establishment of a "no net loss of wetlands" policy continues to constitute one of the major areas of concern to the construction aggregates industry. The other area of concern is related to the final promulgation of the permissible exposure limit for crystalline silica measured as respirable silica.

DOMESTIC DATA COVERAGE

Domestic production data for construction sand and gravel are developed by the U.S. Bureau of Mines from voluntary surveys of U.S. producers. Full surveys of construction sand and gravel producers are conducted for even-numbered years only. For odd-numbered years, only annual estimates for each State are generated based on information provided by the quarterly sample survey of construction sand and gravel and crushed stone producers. This survey provides production estimates by quarters for each State and the nine geographic regions. The sample surveys canvass most of the large companies in each State, accounting for up to 80% of each State's total tonnage. The results of this survey are published each quarter in a separate publication, the quarterly Mineral Industry Surveys.

BACKGROUND

Sand and gravel is a granular, unconsolidated, and usually rounded agglomeration of particles of rocks and

minerals, resulting primarily from the natural disintegration and abrasion of rocks through weathering or erosion. Sand and gravel, as one of the most accessible natural resources, has been used since the earliest days of civilization, mostly as a construction material. At the beginning of the 20th century, the U.S. production of construction sand and gravel, the sand and gravel used mostly for construction purposes, was relatively small and its uses limited. Today, annual sand and gravel production tonnage ranks second in the nonfuel minerals industry after crushed stone and is the only mineral commodity produced in all 50 States. The United States is, in general, self-sufficient in sand and gravel, producing enough to meet all domestic needs and to be a small net exporter, mainly to consumption points along the United States-Canadian and United States-Mexican borders.

Most sand and gravel is used for construction purposes, mainly as aggregate in concrete; as road base material in the construction and repair of highways, railways, and runways; and as aggregate in asphaltic concrete for paving highways, streets, etc. Construction sand and gravel has one of the lowest average per ton values of all mineral commodities. The constant dollar price has changed relatively little over the past 20 years. Increased operating costs have been partially offset by automation and other means of increasing operating efficiency.

Although construction sand and gravel resources are widespread and in adequate supply nationally, local shortages exist. Land use conflicts and environmental

problems associated with rapid urban expansion are major factors contributing to these shortages. In addition, in some geographic areas with sufficient resources, some shortages occur because the proportions of various size fractions of sand or gravel may not meet size specifications of the construction industry. Demand pressures, land use regulations, and the cost of meeting environmental and reclamation requirements are factors that will cause a rising price trend. Larger operations with more efficient equipment, more automation, and better planning and design will be the trend of the industry in the future. This will permit increased use of less accessible and lower quality deposits and will keep prices at competitive levels.

Definitions, Grades, and Specifications

Sand is defined throughout the industry and by the American Society for Testing and Materials (ASTM) as naturally occurring unconsolidated or poorly consolidated rock particles that pass through a No. 4-mesh (4.75-millimeter) U.S. standard sieve and are retained on a No. 200-mesh (75-micrometers) U.S. standard sieve. Gravel consists of naturally occurring unconsolidated or poorly consolidated rock particles that pass through a sieve with 3-inch (76.2-millimeters) square openings and are retained on a No. 4-mesh U.S. standard sieve.

Sand and gravel is made up of varying amounts of different rock types and is, therefore, of varying chemical composition. Silica is the major constituent of most commercial sands, and lesser amounts of feldspar, mica, iron oxides, and heavy minerals are common. Most applications of sand and gravel have specifications for size, physical characteristics, and chemical composition. A compilation of 42 ASTM specifications and test methods, including the latest revisions and updates pertaining to aggregates, concrete, and admixtures, was reprinted by the National Aggregates Association (NAA).¹

Specifications for sand and gravel used in roadbuilding and concrete construction are often rigid regarding particle size gradation and shape and include physical as well as some chemical properties. However, these specifications can differ in detail from State to State or even from city to city within the State. Soil conditions, climate, and peculiarities in different deposits may necessitate adjustments of requirements of sand and gravel mixtures and chemical composition.

Specifications are written by commercial users; Government agencies, including Federal; State, county, and city construction and highway departments; and the ASTM. Problems arise for the producers of construction aggregates when their product is sold or used in several different cities, counties, or States, many of which may have different specifications. Some progress is being made toward the standardization of aggregate sizes for similar requirements. A need exists for a more active interchange of data and experience among aggregate consumers and producers.

Products for Trade and Industry

Concrete is made by mixing properly sized aggregate, portland cement, and water into a slurry. Chemical action between the cement and the water results in the crystallization of hydrous calcium aluminum silicates, which causes the mass to bind and harden. Round particles in the aggregate are desirable because they improve the workability of the concrete as it is poured. If broken material is used and angular or flattish fragments exceed about 15% of the total volume, workability can be maintained only by increasing the amount of sand and water, thus reducing strength, or by adding more cement, thus increasing the cost of the concrete.

Sized and broken sand and gravel is used to make asphaltic concrete aggregate and road bases. Broken surfaces adhere to the hot asphaltic mixture better than do rounded surfaces and provide interlocking surfaces that tend to strengthen the asphaltic concrete. Broken particles pack

better and tend to move less under load than do rounded particles and, therefore, make better road bases for highway and road construction. This is essential because bases and asphaltic concrete tend to flow when placed under great or long duration stresses.

Industry Structure

Because of the low unit value, construction sand and gravel is produced near the point of use; therefore, the industry is concentrated in or nearby large, rapidly expanding urban areas and, on a transitory basis, in areas where highways, dams, and other large-scale public and private works are under construction. In the United States, sand and gravel is produced in every State. The largest operations tend to be concentrated in the States with the largest population and largest production of sand and gravel.

Construction sand and gravel is produced in virtually all countries, but relatively few of them survey this industry and even fewer regularly publish official statistics on sand and gravel.

On the basis of tonnage, the construction sand and gravel industry is the second largest nonfuel mineral industry in the United States. In 1990, the last year when a full survey was conducted, there were 4,094 companies producing construction sand and gravel operating 5,665 pits. The individual operations range in size from those producing millions of tons annually to those reporting less than 25,000 tons per year. Most operations are small, turning out one product or a limited range of products, but most of the tonnage comes from large operations. For example, the 18 operations reporting more than 2.5 million tons each in 1990 represented only 0.3% of the total number of operations, but produced 8% of the total tonnage, while 101 operations reporting between 1 and 2.5 million tons each, representing only 1.8% of the total number of operations, produced 15.5% of the total tonnage. For the same year, most of the construction sand and gravel was produced by operations reporting

between 200,000 and 1 million tons each—1,094 operations, representing 19.2%, produced 49.2% of the total tonnage.

The leading companies producing construction sand and gravel, in descending order of tonnage, based on the 1990 survey, were Beazer U.S.A. Inc. of Pittsburgh, PA; CalMat Co. of Los Angeles, CA; CSR Ltd., of Sydney, Australia; Ashland Oil, Inc., of Ashland, KY; and Dravo Basic Materials Co. of St. Rose, LA. The top 5 companies operated 133 pits and produced 11% of the U.S. total. Two of these five companies are subsidiaries of foreign companies. Many producers are in the sand and gravel business exclusively, but others are diversified in various degrees in the production of other mineral raw materials; intermediate construction products such as ready-mixed concrete and concrete blocks; final manufactured products; or construction of buildings, roads, and other structures. At the same time, construction companies are entering more and more into the sand and gravel business to integrate their operations.

Geology-Resources

The processes of formation and deposition impart to sands and gravels the physical characteristics that largely determine the commercial value for a particular use and influence the manner of development. The principal types, based on origin, are stream, glacial, residual, marine, and lake. Windblown deposits are of minor importance. Much of the commercial production is from stream deposits, many of which are deficient in the fines required by present-day grading specifications for concrete aggregates. Stream deposits usually exhibit stratification and often large-size gradation. The beds vary in thickness and sometimes have interspersed lenses of clay or fine sand. The degree of roundness and the particle size varies with the hardness and distance transported. Glacial deposits have the least sorting of all transported deposits, while marine and lake deposits exhibit the best sorting with coarse and fine

particles, often well segregated. Residual deposits are found overlying the parent rock and are unstratified mixtures of pebbles, boulders, sand, and clay. They often contain much soft material that prohibits commercial production. Marine or offshore deposits could become more important as inland deposits become depleted or environmentally less desirable to extract. A comprehensive report showing geologic occurrences of potential sources of sand and gravel and crushed stone of the conterminous United States for use as natural aggregates was published by the U.S. Geological Survey.²

On the basis of geologic evidence, world reserves are sufficient to meet demands, although not necessarily at precisely the locations where needed. Reserves, which are measurable amounts of sand and gravel that can be produced profitably with current technology under existing economic and political conditions, are controlled mostly by land-use and/or environmental constraints. The total sand and gravel resources of the United States are very large. However, the geographic distribution and/or quality of the reserve base often does not match market patterns or requirements.

Technology

Major technological developments that have been instrumental in maintaining adequate production at relatively stable real costs include use of larger operating units, more efficient portable and semiportable plants, unitized plants for versatility of plant capacity, new prospecting methods utilizing aerial and geophysical surveying methods, and greatly increased rehabilitation and resale of mined areas. Use of mined-out pits as lake beds and as sanitary landfill areas has been successful at numerous localities. Automatic controls, along with monitoring by closed-circuit television coordinated with automated counting and recording and radio communications systems, have been installed in many of the larger and newer operations; these, along with the use of improved equipment, have permitted recovery of

salable fractions from deposits previously considered too low in quality for profitable exploitation. These practices will increase as pressures build to increase productivity and minimize environmental conflicts.

Exploration.—Sand and gravel deposits, like any mineral deposit, must be explored and evaluated before development. Preliminary examination can establish the extent and nature of the deposits. This is followed by a detailed exploration program aimed at obtaining reasonably accurate information on the quantity of material available, the degree of uniformity throughout the deposit, and especially, variations in particle size, both vertically and horizontally. Also, the nature and amount of waste materials and the economic feasibility of their removal must be studied.

Geophysical methods are of value in preliminary surveys. Detailed exploration may be achieved by a systematic arrangement of test pits, trenches, boreholes, or other procedures designed to obtain a cross section of the deposit in conjunction with sampling and testing. Advances in interpretation of aerial photographs and increased application of geophysical techniques have made evaluation of sand and gravel deposits more quantitative. For underwater exploration, mining devices such as dredges and draglines are used. Pilot runs are necessary to determine if required specifications can be met consistently and economically.

Much of the sand and gravel that is being mined in stream, flood plain, alluvial fan, riverbeds and terrain, and glacial deposits is good quality material with nearly equal amounts of gravel and sand and small amounts of unusable material. As these deposits become depleted in future years, less desirable and more expensive sources will have to be developed where mining, reserves, ratio of sand to gravel, quality of material, waste factors, and environmental factors such as waste disposal will present more problems.

Exploration and planning will become more important in assessing deposits,

particularly hillslope deposits of older sand and gravel. Grading to meet required slope and setback requirements at hillslope sites may necessitate leaving large tonnages of material unmined. Many millions of tons of material is available, but it may not be of proper quality or ratio of sand to gravel. More deposits of marginal quality will have to be developed to provide for future demand.

Mining.—Sand and gravel generally occur in the same deposit, but the relative proportions of each vary greatly within most deposits. Consequently, the control problem of producing aggregate to rigid specifications involves combinations of many types of equipment like screens, washers, classifiers, crushers, and grinding mills. The two basic sand and gravel mining methods are open pit excavation and dredging. Open pit excavation and processing has four major steps: (1) site clearing—removing trees and vegetation; stripping overburden and topsoil; and transporting, redepositing, or stockpiling it at or off the site; (2) mining—removing the sand and gravel from the deposit; (3) processing—screening, washing, crushing, blending, and stockpiling the mined material to conform to standards and specifications; and (4) reclamation of the extraction area. Processing may or may not take place at the mining site. Mining equipment ranges from small, simple units such as tractor-mounted high-loaders and dump trucks to more sophisticated systems involving large power shovels, draglines, bucketwheel excavators, and belt conveyors. Increasingly, mining systems are being designed to provide for more efficient and economical land reclamation.

Mining with a dredge usually involves mounting the equipment on boats or barges. Suction or bucket-type dredges are used most commonly to harvest sand and gravel from the bottom of a body of water. The sand and gravel is processed either on board or transported to land for processing.

Processing.—Although small amounts of unprocessed bank-run sand and gravel are used for fill, most of the U.S. production is processed in some way. Present methods include washing with water during the screening process, in some cases followed by crushing of the larger particles in cone or gyratory crushers. Secondary crushing may be done by roll crushers. Sizing is done in most plants by horizontal or sloped single or multideck vibratory screens. If necessary, heavy-media separation or jigging is used to remove heavy, unusable materials. Sand for use in construction is freed from clay by log washers or rotary scrubbers. The scrubbing is followed by classification, use of separatory cones or hydroseparators to remove water, and fine screening for grading. Rodmilling is often required for production of small-sized fractions of sand. Transfer of processed sand and gravel from the processing plant to stockpiles or bins is accomplished by flexible combinations of conveyor belts, bucket elevators, and screw conveyors.

Permanent installations are built when large deposits are to be operated for many years. Portable and semiportable units are used in many pits that have an intermediate working life. Several such units can be tied together to obtain large initial production capacity or to add capacity as needed. Mobile screening plants can be quickly moved from one deposit to another without undue interruption or loss of production.

Recycling.—As the Nation moves into an age of increased environmental consciousness, recycling of old concrete and asphalt, used mostly in pavements, is increasing. Local scarcity or high cost of construction aggregates in some areas as well as waste disposal problems are making recycling more attractive economically. In some States, limited recycling, especially in road construction, is either encouraged or required by law. The best utilization for recycled cement concrete is as road base material, because the matrix of concrete cannot be converted back to cement, and also

because of the lower strength of concrete compared with that of natural aggregates. Sound crushed concrete can make good coarse aggregate, but the fines produced in crushing the concrete have a higher absorption, are more friable, and will require a higher amount of asphalt in asphaltic concrete and a higher amount of mixing water in portland cement.³ The amount of asphalt roads recycled is significantly larger than that of concrete roads, mainly because asphalt can be rejuvenated with oil additives and used in pavements, significantly reducing the cost of the finished road. Experience has shown that about 35% of crushed asphalt pavement can be recycled into new asphalt mixtures. Proper testing under engineering supervision in all construction projects using recycled materials as aggregates should be performed to ensure that the technical specifications are met.

Byproducts and Coproducts

Small amounts of gold and silver are recovered as a byproduct or coproduct of sand and gravel extraction, particularly in highly sorted deposits.

Economic Factors

Construction sand and gravel is a high-volume, low-value commodity. The industry is highly competitive and is characterized by thousands of operations serving local or regional markets. Production costs vary widely depending on geographic location, the nature of the deposit, and the number and type of products produced. Constant dollar unit values have been quite steady during the past 20 years. As a result of rising costs of labor, energy, and mining and processing equipment, the average unit price of construction sand and gravel increased from \$1.1 per ton, f.o.b. plant, in 1970 to \$3.60 in 1991. However, the unit price in constant 1987 dollars fluctuated between a maximum of \$3.06 in 1980 and a minimum of \$2.58 in 1991. (See table 2 and figure 2.) Increased productivity achieved through increased use of automation and more efficient equipment was mainly responsible for

maintaining the prices at this level. Constant dollar prices are expected to rise in the future because of decreased deposit quality and more stringent environmental and land use regulations.

Accessibility is a problem for the construction sand and gravel industry. The high-volume and low-unit value of sand and gravel requires that operations be close to the market location. Markets for sand and gravel are construction sites that are mostly in areas of high population density. New operations, close to population centers, are difficult to develop because the land is often attractive for other uses such as housing, shopping centers, agriculture, parks or recreational areas, and because of public dislike for mining operations close to populated areas. Existing operations in expanding communities face increasing costs because of increasing land values and increasing restrictions on operations as suburban development comes closer. Deposits are often small and, once exhausted, the operation must be moved to a new site that invariably is farther from the market because closer sites are being used for other purposes.

The industry also faces increasing competition from crushed stone that can substitute for sand and gravel in most of its applications. Stone operations are generally longer lived, can afford greater capital investment for higher efficiency, and are often located where competing land use pressures are less severe. The topographically rugged stone-bearing areas are usually less desirable for construction purposes than sand-and-gravel-bearing areas, which are generally flatter.

A 5% depletion allowance based on gross income is allowed for construction sand and gravel. There are no import tariffs.

Operating Factors

Many States, counties, and cities in the United States have zoning laws, and land within each governmental unit is usually zoned to indicate acceptable land uses. If mining is permitted in a zone and a sand and gravel company owns or leases land

within that zone, the company may apply for a use permit or its equivalent to begin an operation. If the parcels to be quarried are on lands under both city and county jurisdiction, permits usually must be obtained from each. An acceptable reclamation plan that meets the guidelines or regulations of the appropriate governmental agency must also be approved. Environmental concerns such as noise, dust, beautification, and storage of wastes must be accounted for in a manner satisfactory to the governmental entity involved. Wastewater discharge requirements must be planned for and met. If the deposit to be worked is on a river or land controlled by a river or water or flood control agency, whether municipal, State, or Federal, that agency's requirement must also be satisfied.

In most States, permits for sand and gravel operations require an Environmental Impact Report (EIR) or Statement (EIS). A reclamation plan and a use permit application may also be required, with considerable overlap of subject matter with the EIS. A complete EIS may cover all the problem areas at once and facilitate acceptance.

Environmental Requirements.—Two main points are involved in environmental land use and reclamation factors. First, the industry must be concerned about any practices that can affect the community environment. An effective effort must be made to reduce noise, air, and water pollution; to reclaim pits after the operation is complete; and to improve the overall appearance of the operating mine, processing plant, and transportation facilities. Second, the industry and community must recognize the time and costs required to protect the environment and the importance of agreeing on fair and realistic environmental standards.

Because sand and gravel is a local commodity, the effect of supply deficiencies and cost of material will affect the local community first. Undue delay and unreasonably high cost can strongly affect the movement of sand and gravel into the marketplace. Also, stringent controls by the local government

that prevent permits being issued to operators can have adverse economic effects on the communities around them. These conditions can make it difficult to assess the timing and even the possibility of plants going on-stream and can therefore affect the supply of sand and gravel into the marketplace.

Although much progress is being made through premining planning, the sand and gravel industry continues to have problems with environmental controls, land use conflicts, and reclamation practices. Many of these problems are acute because extraction areas and plants must be reasonably near to consumers who are largely in metropolitan areas. Major environmental considerations that must be dealt with in mining and processing sand and gravel are emission of particulate matter into the air, processing water discharge, noise abatement, and employee and public health and safety.

Transportation.—Transportation is a major factor in the delivered price of construction sand and gravel. The cost of moving construction sand and gravel from the plant to the market often exceeds the sales price of the product at the plant. Because of the high cost of transportation, construction sand and gravel continues to be marketed locally. Economies of scale, which might be realized if fewer, larger operations served larger marketing areas, would probably not offset the increased transportation costs.

Truck haulage is the main form of transportation used in the construction sand and gravel industry. Many producers have their own truck fleet and deliver their own raw materials and products. A significant and increasing amount of sand and gravel, however, is being hauled by independent truckers because of the cost of maintaining a truck fleet, particularly when the market is highly variable or down. Rail and water transportation combined account for about 10% to 20% of total construction sand and gravel shipments.

ANNUAL REVIEW

In 1991, a total of 780 million short tons of construction sand and gravel was estimated to have been produced in the United States, a 14.3% decrease compared with the total production of 1990. This tonnage represents the lowest production level since 1986, indicating a significant decline in the demand for construction aggregates in the United States in 1991. During the year, productions of construction sand and gravel decreased every quarter, compared with the same period of 1990, with the largest decreases occurring in the first and fourth quarters of 1991.

Legislation

On December 18, 1991, the Intermodal Surface Transportation and Infrastructure Act of 1991 became Public Law 102-240. The new law authorized \$151 billion to be spent in the next 6 years on transportation projects, \$119.5 billion on highway work, and \$32.5 billion on mass transit. The new law defines a new National Highway System that combines interstate routes with selected State routes, creates a Surface Transportation Program that replaces categorical grants to the States, and restructures the Federal-Aid Highway Program giving State legislatures and metropolitan planning organizations more flexibility in choosing projects and transferring funds between spending categories.

On June 8, 1992, OSHA announced that it was amending its standards governing the "Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite (AT&A)"⁴ by removing nonasbestiform AT&T from the scope of the present standards affecting the general industries, including the construction industries. OSHA has determined that substantial evidence is lacking to conclude that AT&T present the same type or magnitude of health effects as asbestos or that employees would be at significant risk because nonasbestiform AT&T were not regulated in the asbestos standards. The latest Administrative Stay of

enforcement of the revised standards was also removed by OSHA effective May 29, 1992.

Issues

The implementation of the provisions of the amended Federal Water Pollution Control Act of 1977, the Clean Water Act, Section 404, dealing with "wetlands" and the establishment of a "no net loss of wetlands" policy constitutes one of the major areas of concern to the crushed stone industry. There is a significant amount of uncertainty regarding the process of designating some lands as wetlands and whether the current exemptions to the Clean Water Act section 404 permit program will be maintained in the future. Several bills were introduced in the 102d U.S. Congress to replace the current section 404 of the Federal Water Pollution Control Act. The new proposed bills plan to provide a concise and structured program for the delineation of wetlands based upon their functions and values and will balance the need for effective protection of the Nation's important wetlands with the need for essential community growth and the constitutional rights of landowners.

The removal of nonasbestiform AT&T from the scope of the present OSHA standards for regulating occupational exposure to asbestos in general industries, including the construction industries, eliminates a major area of concern for the construction aggregates industries. Based on the entire rulemaking record, OSHA has determined that substantial evidence is lacking to conclude that nonasbestiform AT&T present the same type or magnitude of health effects as asbestos. OSHA also concluded that substantial evidence does not support a finding that exposed employees would be at significant risk because nonasbestiform AT&T were not regulated in the asbestos standard.

Another issue of concern to the construction aggregates industries is the classification of crystalline silica as a probable human carcinogen by the International Agency for Research on

Cancer, an agency of the World Health Organization. OSHA-regulated sites that receive and/or use products containing more than 0.1% crystalline silica must comply with OSHA's Hazard Communication Standard. Both the classification of crystalline silica as a probable human carcinogen and the requirement to quantitatively analyze for crystalline silica at the 0.1% level are controversial.

Production

The production estimates indicate that in 1991 the U.S. production of construction sand and gravel was 780 million short tons, a 14.3% decrease compared with the total production of 1990. Of the four major geographic regions, the West again led the Nation in the production of construction sand and gravel with 285 million tons or 36.5% of the U.S. total, followed by the Midwest with 244 million tons or 31.2% of the total; the South with 171 million tons or 21.9%; and the Northeast with 81 million tons or 10.3%. Compared with that of 1990, production by major geographic regions decreased in every region, 24.3% in the Northeast, 16.1% in the South, 13.5% in the Midwest, and 10.3% in the West. (See table 3 and figure 1.)

Of the nine geographic regions, the Pacific again led the Nation with 172 million tons or 22.1% of the U.S. total. Next was the East North Central with 161 million tons or 20.7% of the total, and the Mountain with 113 million tons or 14.4% of the total. Compared with that of 1990, production decreased in all nine regions, the largest decreases being recorded in the New England region, 33.5%; the South Atlantic region, 20%; and the Middle Atlantic region with only 18.9%. (See table 3.)

The estimated production by quarters for 1991 indicated that most of the construction sand and gravel in the United States was produced in the third quarter, followed by the second quarter and the fourth quarter. Estimated production by each quarter of 1991 was also available for most of the States. (See tables 4 and 6.)

Construction sand and gravel was produced in every State, and the 10 leading States in 1991 were, in descending order of tonnage, California, Michigan, Ohio, Washington, Texas, Wisconsin, Colorado, Illinois, Minnesota, and New York. Their combined production represented 51.1% of the national total. (See table 5.)

Compared with that of 1990, production decreased in most States, including 7 of the top 10 States. The decreases, in percentage, were very large in Maine, -50.4%, New Hampshire, -40.5%, Connecticut, -36.8%, and Rhode Island, -34%, and significant in some of the major producing States like Minnesota, -27.7%, California, -22.9%, New York, -20.3%, Illinois, -18.8%, Michigan, -16.6%, and Texas, -15.8%.

Limited information about the production of construction sand and gravel in foreign countries may be found in the U.S. Bureau of Mines "Minerals Yearbook, Area Reports: International." For nonreporting countries, estimates of sand and gravel and crushed stone outputs can be based on indirect sources such as the level of cement consumption.

Fewer changes in ownership, acquisitions by foreign or domestic companies, and mergers occurred in the construction sand and gravel industry in 1991. In November 1991, Hanson PLC of London, United Kingdom, acquired Beazer PLC, of Bath, United Kingdom, the parent company of Beazer USA, Inc., the largest construction sand and gravel and the second largest crushed stone producer in the United States. In August, prior to the acquisition, in an effort to reduce its debt, Beazer announced plans to sell most of its European housebuilding, real estate, and contracting operations and focus mostly on its U.S.-based operations.

In October 1991, Redland Aggregates Ltd. of Groby, Leicester, United Kingdom, acquired Frontier Materials Co. of Denver, CO, a sand and gravel producer and a paving company.

Consumption and Uses

Sand and gravel reported by producers to the U.S. Bureau of Mines is actually material that is "sold or used" by the companies and is defined as such. Stockpiled production is not reported until it is sold to a user or consumed by the producer outside its own operation. Because no consumption surveys are conducted by the U.S. Bureau of Mines, the "sold or used" tonnage is assumed to represent the amount produced for domestic consumption and export.

The largest use of construction sand and gravel is as aggregate for the production of concrete, used in nearly all residential, commercial, and industrial buildings, and in most public works projects such as highways and roads, bridges, dams, airport runways, sewer systems, tunnels, etc.

Over the past several years, this use represented about 26% of the total. The second largest use is as base material in the construction and repair of highways, railways, runways, etc. It represented about 15% of the total. Other major uses are as aggregate in asphaltic concrete used for paving highways, streets, and parking lots, about 8%, and as fill in highway construction, earth dams, and other applications where recontouring of the original land surface is required, about 7%. The above percentages were calculated based on the information provided by the producers. It should be noted that over the past several years, about 37% of the total U.S. production was included in "unspecified uses—actual and estimated," because some producers reported only total production or did not report at all, and then their production was estimated. The percentage of estimated amounts for nonrespondents decreased from 23.5% in 1984 to 12.7% in 1990, while the percentage of production reported only as totals increased from 16.2% in 1984 to 24.1% in 1990.

Sand and gravel are usually used mixed, but some uses require only sand or only gravel. Sand is used in mortar, plaster, and gunite and for snow and ice control. Gravel is used to improve or

control drainage and as covering and stabilizer on load-bearing surfaces such as unpaved roads, driveways, and parking areas. In 1991, only production estimates were generated for construction sand and gravel, and therefore no information by end uses is available for this year.

Prices

Prices in this chapter are f.o.b. plant, usually at the first point of sale or captive use. This value does not include transportation from the plant or yard to the consumer. It does, however, include all costs of mining, processing, in-plant transportation, overhead costs, and profit. Compared with that of 1990, when the last full annual survey was conducted, the estimated 1991 average unit prices increased only 0.8% to \$3.60 per ton.

As a result of rising costs of labor, energy, and mining and processing equipment, the average unit value of construction sand and gravel increased from \$1.11 per ton, f.o.b. plant, in 1970, to \$3.60 in 1991. However, the unit price in constant 1987 dollars fluctuated between a maximum of \$3.06 in 1980 and a minimum of \$2.58 in 1991. (See table 2.)

Foreign Trade

The widespread distribution of domestic sand and gravel deposits and the high cost of transportation limits foreign trade, mostly to local transactions across international boundaries. U.S. imports and exports are small, representing less than 1% of the domestic consumption.

Exports.—Exports of construction sand decreased 6.2% to 439,000 tons, while value increased 9.4% to \$13 million. Mexico was the major destination, receiving 41.9% of the total, followed by Canada with 37.1%. Exports of construction gravel declined 17.8% to 700,000 tons compared with those of 1989, and value declined 21.6% to \$6 million, again compared with that of 1989, because no information on exports of gravel was available for 1990. Canada was the major destination with 84.6% of

the total, followed by Mexico with 4.7%. (See table 8.)

Imports.—Imports of construction sand and gravel decreased 15.9% to 1.5 million tons compared with that of 1990, while the value decreased 27.4% to \$16.6 million. Canada was the major source of imported construction sand and gravel with 65.2% of the total, followed by the Bahamas with 18.4%. (See table 9.)

Current Research

Recognizing the need for research into properties and adequate use of aggregates, crushed stone, and sand and gravel, as well as the need for reliable technical information in this area, the National Aggregates Association and the National Stone Association established in 1990 the Aggregates Foundation for Technology, Research, and Education (AFTRE.) The main purpose of the Foundation is to establish and provide the funding for the Aggregates Research Center. The Foundation and the Research Center will support scientific research and education and develop and disseminate authoritative technical information related to construction aggregates. The comprehensive and objective information on construction aggregates developed by the Research Center will promote and extend the effective and efficient use of aggregates in the construction industries. At the 1992 CON/AGG Show held in New Orleans, LA, between February 1 through February 6, 1992, the Board of Trustees of AFTRE announced the selection of the University of Texas at Austin and the Texas A&M University at College Station as the home of the new Aggregates Research Center.

The year 1991 was the fourth year of the 5-year Strategic Highway Research Program (SHRP), a program created in 1987 by the U.S. Congress. SHRP's mission is to produce usable research results targeted toward technical areas where there is potential for improvement of our highways and the materials used to build them, research that could also yield significant cost savings. SHRP's

research activities account today for more than one-quarter of all highway research conducted in the United States by the Federal agencies, the States, and the private industry.

SHRP's four areas of research are asphalt, concrete and structures, highway operations, and long-term pavement performance. To improve the quality of pavements, better materials specifications and asphalt concrete mixture design systems based on a scientific understanding of how asphalt properties influence performance are needed. SHRP made significant progress toward that goal in 1991.⁵

Based on results obtained through the use of state-of-the-art chemical and physical analysis techniques, researchers supported by SHRP have developed a chemical model of asphalt structure that, for the first time, explains how asphalt chemistry affects binder performance. Analysis of samples of asphalt using nuclear magnetic resonance spectroscopy (NMR) indicated that the molecular structures in asphalt are very small, contrary to the long-accepted "micellar" model that had pictured asphalt as relatively large lumps of materials in a sticky gel. At the same time, chemical analysis using ion exchange chromatography indicated that the molecules that gave the asphalt most of its physical properties comprised only a small portion of the total number of asphalt molecules. Based on these results, a model was produced that describes asphalt as a polar dispersed fluid and reconciles asphalt's chemical features with its physical behavior.

SHRP's concrete program is developing new engineering guidelines and materials tests that will help highway engineers produce more durable concrete consistently. Alkali-Silica Reactivity (ASR) of concrete is a damaging and difficult-to-detect problem in highway structures and a major area of concern for the highway and bridge inspectors. SHRP's Construction Technology Laboratories developed a new quick chemical field test that uses uranyl acetate fluorescence to detect whether an ASR product has been formed in concrete.

SHRP's Handbook for the Identification of Alkali-Silica Reactivity in Highway Structures provides guidance on proper diagnosis and assessment of ASR problems.⁶

SHRP's Long-Term Pavement Performance (LTPP) program addresses the issue of how best to use and protect the very large investment made every year in building and maintaining highway pavements. SHRP's LTPP program, the largest and most comprehensive pavement performance test in history, is collecting data on pavement conditions, climate, traffic, and load conditions over a 20-year period. The LTPP experiments involve testing of almost 1,000 in-service sections of the most common types of pavement design in use in the United States, as well as sections that have been specially constructed to isolate certain factors in pavement design.

The American Association of State Highway and Transportation Officials, the Federal Highway Administration, and the National Research Council have agreed upon an approach to establish an oversight of continuing activities when some of SHRP's programs expire in 1992. The SHRP Monitoring and Research Transfer Committee will be created by the National Research Council that will include representatives from a broad spectrum of organizations, including strong State highway agency representation.

Technology

A bucket-wheel dredge of a new design that can operate at depths of up to 30 to 35 meters, (97 to 107 feet), replaced a plain suction dredge in the Netherlands. In addition to being able to dredge at significantly greater depths than its predecessor, the new dredge has also doubled its production and cut fuel consumption in half. The dredge throughput can reach 1,200 cubic meters/hour, (1,570 cubic yards) of slurry at densities of up to 1.7 (70% solids). The heart of the dredge is a 1.90-meter diameter bucket-wheel driven by a 75-kilowatt hydraulic motor at speeds of up to 25 revolutions per

minute. The buckets of the bucket-wheel are closely spaced and have no bottom or rear and are a part of the suction mouth. A 250-kilowatt submerged pump on the ladder lifts the excavated slurry to a 443-kilowatt on-board booster pump for transfer through a 350-millimeter-diameter floating pipeline to the processing plant. The dredge can be operated by only one person. The Series 1400 wheel dredge was manufactured by IHC Holland NV. A new dredge of the same basic design that will be able to excavate at even greater depths of up to 54 meters is presently under construction.⁷

Specialized computer services using high technology provide fast and accurate earthwork volume estimating that are being used to calculate production and stock inventories in aggregates operations. Computer generated cross sections of the pit or quarry at very close intervals are generated, and very accurate calculations of volumes are performed. Valuable three-dimensional depth maps and two-dimensional cross sections of the operations can be also produced that can assist the plant operators or the designers of new pits and quarries.⁸

More aggregates-producing companies are automating their operations to remain competitive. Automated weighing and information processing systems in the sand and gravel and crushed stone industries are usually one of the first areas to be automated, especially in medium- to small-size operations. A properly selected and implemented computer-based data collection, storage, retrieval, and reporting system provides the operations with fewer mistakes, reduced expenses, and more timely available information. A review of present technology, software and hardware, and recommendations on how to select and implement the proper system in aggregates operations was published by Pit & Quarry.⁹

Technologically, the aggregates industry is very complex and requires professionals with skills in a variety of areas, including geology and geophysical sciences, mining, materials, and geotechnical engineering and

management. For a long time there has been a need for a comprehensive reference book covering the construction aggregates that can be used by producers, consulting and design engineers, and users. The Aggregate Handbook published by the National Stone Association in 1991 is just such a publication. The handbook covers all aspects of the sand and gravel and crushed stone industries from basic properties of aggregates, geology, exploration, extraction, and processing, to uses, standards and specifications, sampling and testing, marketing, and regulatory compliance. Numerous references are also provided for those interested for more in-depth information.¹⁰

OUTLOOK

The demand for construction sand and gravel in 1992 is expected to be about 850 million tons, a 9% increase from that of 1991. Gradual increases in demand for construction aggregates are anticipated after 1992, based on increased volume of work on the infrastructure expected to occur following the passage of the Intermodal Surface Transportation and Infrastructure Act of 1991. The new law authorized \$151 billion to be spent in the next 6 years on transportation projects, of which \$119.5 billion was on highway work and \$32.5 billion was on mass transit. It is estimated that the demand for construction sand and gravel will reach 1 billion tons in 1995. The projected increases will be influenced by construction activity primarily in the public construction sector and to a lesser extent in the private sector.

The value of public construction work as part of the gross domestic product (GDP) has declined constantly, from about 3% in the 1950's and 60's to less than 2% in the 1980's. If this trend begins to reverse in the 1990's, a significant increase in spending for public construction work could be expected that will dramatically alter the aforementioned forecasts.

Construction sand and gravel f.o.b. prices are not expected to increase

significantly, even if the demand for construction aggregates will rise over the aforementioned forecasts. However, the delivered prices of construction sand and gravel are expected to increase, especially in and near metropolitan areas, mainly because more aggregates are transported from distant sources.

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TABLE 1
SALIENT U.S. CONSTRUCTION SAND AND GRAVEL STATISTICS

		1987	1988	1989	1990	1991
Sold or used by producers:						
Quantity ¹	thousand short tons	*896,200	923,400	*897,300	910,600	*780,300
Quantity	thousand metric tons ²	813,019	837,695	814,017	826,083	707,876
Value ¹	thousand dollars	*\$3,002,500	\$3,126,000	*\$3,249,100	\$3,249,400	*\$2,805,500
Exports	value, thousand dollars	\$10,533	\$11,048	\$13,591	\$11,880	\$19,044
Imports	do.	\$2,367	\$3,163	\$6,618	\$22,912	\$16,638

*Estimated.

¹Puerto Rico excluded from all sand and gravel statistics.

²One metric ton is equal to 2,204.6 lbs. To convert from short tons to metric tons, multiply short tons by 0.907185.

TABLE 2
TIME-PRICE RELATIONSHIPS
FOR CONSTRUCTION SAND AND
GRAVEL

Year	Actual unit prices	Unit prices in 1987 constant dollars	Unit prices in 1970 constant dollars
1970	1.11	2.65	1.11
1971	1.18	2.67	1.12
1972	1.23	2.66	1.11
1973	1.31	2.66	1.11
1974	1.46	2.72	1.14
1975	1.56	2.66	1.11
1976	1.88	3.01	1.26
1977	2.02	3.03	1.27
1978	2.13	2.96	1.24
1979	2.27	2.90	1.22
1980	2.62	3.06	1.28
1981*	2.79	2.96	1.24
1982	2.82	2.82	1.18
1983*	2.95	2.83	1.19
1984	2.90	2.67	1.12
1985*	3.05	2.71	1.13
1986	3.11	2.69	1.13
1987*	3.35	2.81	1.18
1988	3.39	2.73	1.15
1989*	3.62	2.80	1.17
1990	3.57	2.65	1.11
1991	3.60	2.58	1.08

*Estimated.

**TABLE 3
CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY
GEOGRAPHIC REGION**

Geographic region	1990				1991*			
	Quantity (thousand short tons)	Percent of total	Value (thousands)	Percent of total	Quantity (thousand short tons)	Percent of total	Value (thousands)	Percent of total
Northeast:								
New England	42,726	4	\$166,347	3	28,400	4	\$111,100	4
Middle Atlantic	64,495	7	283,118	9	52,300	7	231,200	8
Midwest:								
East North Central	184,113	20	573,815	18	161,100	21	520,600	19
West North Central	97,715	11	244,166	8	82,700	11	216,900	8
South:								
South Atlantic	80,748	9	320,469	10	64,600	8	248,900	9
East South Central	43,555	5	149,115	5	37,000	5	127,000	5
West South Central	79,581	9	271,450	8	69,400	9	238,100	8
West:								
Mountain	113,858	13	376,660	12	112,700	14	377,600	13
Pacific	203,787	22	864,254	27	172,100	22	734,100	26
Total¹	910,600	100	3,249,400	100	780,300	100	2,805,500	100

*Estimated.

¹Data may not add to totals shown because of independent rounding.

**TABLE 4
CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1991, BY
GEOGRAPHIC REGION AND QUARTER¹**

(Thousand short tons and thousand dollars)

Region	Quantity					Value	Number of companies ³
	1st Quarter	2d Quarter	3d Quarter	4th Quarter	Total ²		
Northeast:							
New England	3,000	7,300	8,100	9,000	28,400	111,100	26
Middle Atlantic	7,100	15,000	17,700	13,100	52,300	231,200	32
Midwest:							
East North Central	15,700	46,200	57,000	39,900	161,100	520,600	52
West North Central	7,700	23,700	28,800	20,600	82,700	216,900	49
South:							
South Atlantic	13,500	17,300	18,100	16,300	64,600	248,900	44
East South Central	6,100	9,900	10,900	9,000	37,000	127,000	22
West South Central	14,700	17,400	20,000	17,300	69,400	238,100	19
West:							
Mountain	20,500	29,900	33,500	24,900	112,700	377,600	35
Pacific ⁴	23,500	39,700	47,300	43,100	157,700	692,600	29
Total²	111,800	206,500	241,400	193,200	⁵780,300	²2,805,500	XX

XX Not applicable.

¹As published in the "Crushed Stone and Sand and Gravel in the Fourth Quarter of 1990," Mineral Industry Survey.

²Data may not add to totals shown because of independent rounding, and differences between projected totals by States and by regions.

³Number of companies reporting for the quarterly survey.

⁴Does not include Alaska and Hawaii in quarterly estimates.

TABLE 5
CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand short tons and thousand dollars)

State	1990			1991		
	Quantity	Value	Unit value	Quantity	Value	Unit value
Alabama	14,103	50,243	3.56	12,700	45,700	3.56
Alaska	15,100	41,800	2.77	14,000	39,200	2.77
Arizona	27,915	92,166	3.30	22,500	79,400	3.30
Arkansas	9,663	35,475	3.67	8,300	31,100	3.67
California	132,214	626,000	4.73	101,900	489,100	4.73
Colorado	24,938	86,541	3.47	26,400	88,200	3.47
Connecticut	8,542	37,943	4.44	5,400	24,800	4.44
Delaware	2,184	6,967	3.19	1,600	5,100	3.19
Florida	18,472	59,123	3.20	16,000	51,400	3.20
Georgia	5,158	16,644	3.23	4,700	14,500	3.23
Hawaii	438	2,459	5.61	400	2,300	5.61
Idaho	9,222	25,590	2.77	11,600	31,300	2.77
Illinois	32,380	104,728	3.23	26,300	90,400	3.23
Indiana	23,879	76,886	3.22	18,100	60,400	3.22
Iowa	14,953	46,432	3.11	17,400	55,800	3.11
Kansas	10,863	24,170	2.22	9,600	22,100	2.22
Kentucky	8,802	29,581	3.36	7,700	27,200	3.36
Louisiana	14,589	55,902	3.83	13,300	48,900	3.83
Maine	7,865	29,349	3.73	3,900	14,800	3.73
Maryland	18,271	104,023	5.69	13,000	72,800	5.69
Massachusetts	12,774	51,466	4.03	10,100	39,400	4.03
Michigan	53,729	153,057	2.85	44,800	132,200	2.85
Minnesota	33,869	77,502	2.29	24,500	58,800	2.29
Mississippi	13,032	45,817	3.52	9,900	33,000	3.52
Missouri	9,243	25,097	2.72	7,400	20,100	2.72
Montana	5,114	14,319	2.80	4,800	13,700	2.80
Nebraska	11,453	30,056	2.62	10,100	27,300	2.62
Nevada	18,377	59,008	3.21	20,300	69,000	3.21
New Hampshire	7,901	26,599	3.37	4,700	16,200	3.37
New Jersey	13,862	64,245	4.63	10,300	47,900	4.63
New Mexico	10,362	39,708	3.83	9,200	35,900	3.83
New York	29,750	121,525	4.08	23,700	95,500	4.08
North Carolina	11,733	44,872	3.82	9,900	35,000	3.82
North Dakota	7,644	17,219	2.25	5,000	12,000	2.25
Ohio	44,552	165,394	3.71	42,300	160,100	3.71
Oklahoma	9,235	21,993	2.38	9,000	22,300	2.38
Oregon	15,785	60,928	3.86	15,600	62,800	3.86
Pennsylvania	20,883	97,348	4.66	18,300	87,800	4.66
Rhode Island	1,969	9,042	4.59	1,300	6,000	4.59
South Carolina	8,627	24,941	2.89	6,600	18,900	2.89
South Dakota	9,689	23,689	2.44	8,700	20,800	2.44
Tennessee	7,619	23,474	3.08	6,700	21,100	3.08
Texas	46,093	158,080	3.43	38,800	135,800	3.43

... footnotes at end of table.

TABLE 5—Continued

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand short tons and thousand dollars)

State	1990			1991		
	Quantity	Value	Unit value	Quantity	Value	Unit value
Utah	13,601	44,881	3.30	14,400	48,200	3.30
Vermont	3,675	11,948	3.25	3,000	9,900	3.25
Virginia	13,096	48,950	3.74	9,700	36,900	3.74
Washington	40,251	133,067	3.31	40,200	140,700	3.31
West Virginia	3,208	14,950	4.66	3,100	14,300	4.66
Wisconsin	29,572	73,750	2.49	29,600	77,500	2.49
Wyoming	4,329	14,446	3.34	3,500	11,900	3.34
Total ¹	910,600	3,249,400	3.57	780,300	2,805,500	3.60

¹Estimated.¹Data may not add to totals shown because of independent rounding.

TABLE 6

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1991, BY STATE AND QUARTER¹

(Thousand short tons and thousand dollars)

State	Quantity					Value	Number of companies ³
	1st Quarter	2d Quarter	3d Quarter	4th Quarter	Total ²		
Alabama	2,600	3,500	3,400	3,200	12,700	45,700	9
Alaska ⁴	—	—	—	—	14,000	39,200	—
Arizona	4,900	6,300	6,100	5,200	22,500	79,400	10
Arkansas	1,800	2,100	2,300	2,100	8,300	31,100	4
California	14,600	26,700	31,500	29,100	101,900	489,100	17
Colorado	3,500	6,900	9,300	6,700	26,400	88,200	10
Connecticut	500	1,900	1,400	1,600	5,400	24,800	8
Delaware	300	500	400	400	1,600	5,100	5
Florida	3,800	3,900	4,200	4,100	16,000	51,400	9
Georgia	1,100	1,300	1,200	1,100	4,700	14,500	9
Hawaii ⁴	—	—	—	—	400	2,300	—
Idaho	2,600	1,700	4,700	2,600	11,600	31,300	5
Illinois	2,600	7,700	9,900	6,100	26,300	90,400	8
Indiana	2,300	5,400	6,300	4,100	18,100	60,400	14
Iowa	1,300	5,200	6,700	4,200	17,400	55,800	8
Kansas	1,200	3,300	2,900	2,200	9,600	22,100	10
Kentucky	1,100	2,100	2,500	2,000	7,700	27,200	6
Louisiana	3,000	3,200	3,600	3,500	13,300	48,900	5
Maine	200	1,100	1,100	1,500	3,900	14,800	4
Maryland	2,600	3,400	3,700	3,300	13,000	72,800	10
Massachusetts	1,200	2,300	3,100	3,500	10,100	39,400	7
Michigan	3,300	12,700	16,900	11,900	44,800	132,200	10
Minnesota	2,600	5,700	9,300	6,900	24,500	58,800	17
Mississippi	2,100	2,400	3,000	2,400	9,900	33,000	9
Missouri	900	2,300	2,500	1,700	7,400	20,100	6
Montana ⁴	—	—	—	—	4,800	13,700	—
Nebraska	900	3,700	3,400	2,100	10,100	27,300	8
Nevada	4,800	5,700	5,400	4,400	20,300	69,000	7
New Hampshire	700	1,100	1,400	1,500	4,700	16,200	6
New Jersey	1,600	3,000	3,000	2,700	10,300	47,900	8
New Mexico	1,200	3,300	2,800	1,900	9,200	35,900	4
New York	2,700	5,800	8,700	6,500	23,700	95,500	11
North Carolina	2,100	2,500	2,600	2,700	9,900	35,000	7
North Dakota ⁴	—	—	—	—	5,000	12,000	—
Ohio	4,200	11,900	14,800	11,400	42,300	160,100	14
Oklahoma	2,000	2,300	2,600	2,100	9,000	22,300	8
Oregon	3,100	4,000	4,900	3,600	15,600	62,800	4
Pennsylvania	2,500	5,500	6,200	4,100	18,300	87,800	15
Rhode Island ⁴	—	—	—	—	1,300	6,000	—
South Carolina	1,400	1,600	2,000	1,600	6,600	18,900	6
South Dakota	200	2,900	3,500	2,100	8,700	20,800	7

See footnotes at end of table.

TABLE 6—Continued
**CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1991,
 BY STATE AND QUARTER¹**

(Thousand short tons and thousand dollars)

State	Quantity					Value	Number of companies ³
	1st Quarter	2d Quarter	3d Quarter	4th Quarter	Total ²		
Tennessee	1,100	2,100	2,100	1,400	6,700	21,100	7
Texas	7,900	9,800	11,800	9,300	38,800	135,800	13
Utah	1,200	4,300	5,600	3,300	14,400	48,200	5
Vermont	200	700	1,100	1,000	3,000	9,900	5
Virginia	1,700	2,900	2,800	2,300	9,700	36,900	7
Washington	7,400	9,800	12,000	11,000	40,200	140,700	10
West Virginia	300	1,000	1,000	800	3,100	14,300	5
Wisconsin	3,000	9,100	9,900	7,600	29,600	77,500	13
Wyoming	500	1,000	1,300	700	3,500	11,900	6
Total ²	XX	XX	XX	XX	780,300	2,805,500	XX

XX Not applicable.

¹As published in the "Crushed Stone and Sand and Gravel in the Fourth Quarter of 1990," Mineral Industry Survey.

²Data may not add to totals shown because of independent rounding.

³Number of companies reporting for the quarterly survey.

⁴Owing to a very low number of reporting companies in some States, no production estimates by quarters were generated.

TABLE 7
CONSTRUCTION SAND AND GRAVEL SOLD OR USED IN THE UNITED STATES, BY MAJOR USE

Use	1986			1988			1990		
	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton
Concrete aggregate (including concrete sand)	219,009	\$814,860	\$3.72	230,576	\$887,422	\$3.85	240,076	\$947,843	\$3.95
Plaster and gunitite sands	10,049	39,972	3.98	9,227	43,226	4.68	10,007	43,599	4.36
Concrete products (blocks, bricks, pipe, decorative, etc.)	16,274	55,648	3.42	10,403	38,916	3.74	11,171	45,840	4.10
Asphaltic concrete aggregates and other bituminous mixtures	87,410	322,666	3.69	82,417	318,662	3.87	76,491	326,590	4.27
Road base and coverings	128,112	354,740	2.77	136,597	413,330	3.03	135,642	428,314	3.16
Road stabilization (cement)	1,509	3,928	2.60	2,390	6,452	2.70	1,819	5,198	2.86
Road stabilization (lime)	901	3,342	3.71	984	2,592	2.63	772	2,638	3.42
Fill	66,094	128,780	1.95	62,611	134,709	2.15	73,152	173,624	2.37
Snow and ice control	5,797	17,210	2.97	5,974	20,086	3.36	7,307	24,971	3.42
Railroad ballast	1,512	5,662	3.74	638	2,849	4.47	869	3,590	4.13
Roofing granules	564	3,102	5.50	623	2,517	4.04	566	2,876	5.08
Filtration	—	—	—	69	372	5.39	1,110	6,113	5.51
Other	13,981	55,706	3.98	20,578	72,443	3.52	16,466	58,322	3.54
Unspecified:									
Actual	167,891	539,043	3.21	238,924	828,733	3.47	219,893	837,118	3.81
Estimated	163,900	402,515	2.46	121,352	353,689	2.91	115,237	342,757	2.97
Total ¹ or average	883,000	2,747,200	3.11	923,400	3,126,000	3.39	910,600	3,249,400	3.57

¹Data may not add to totals shown because of independent rounding.

TABLE 8
U.S. EXPORTS OF CONSTRUCTION SAND AND GRAVEL IN 1991,
BY COUNTRY

(Thousand tons and thousand dollars)

Country	Sand		Gravel	
	Quantity	F.a.s. value ¹	Quantity	F.a.s. value ¹
North America:				
British Virgin Islands	(⁰)	5	11	120
Canada	163	2,903	592	2,364
Jamaica	1	148	(⁰)	3
Mexico	184	1,970	33	654
Netherlands Antilles	14	190	13	76
Trinidad And Tobago	1	185	(⁰)	15
Other ²	4	629	22	660
Total⁴	368	6,029	669	3,892
South America:				
Argentina	6	457	—	—
Colombia	3	554	—	—
Peru	2	138	—	—
Venezuela	10	1,063	(⁰)	41
Other	(⁰)	91	—	—
Total⁴	22	2,302	(⁰)	41
Europe:				
Belgium	3	85	—	—
Italy	2	359	—	—
United Kingdom	5	162	(⁰)	22
Other	1	303	1	74
Total	11	909	1	96
Asia:				
Hong Kong	(⁰)	11	4	291
Japan	6	713	3	136
Korea, Republic of	6	1,184	6	237
Singapore	3	397	2	142
Taiwan	(⁰)	64	15	1,133
Other	1	206	(⁰)	16
Total⁴	17	2,575	30	1,955
Oceania:				
Australia	1	161	(⁰)	32
Other	—	—	(⁰)	20
Total	1	161	1	52
Middle East:				
Oman	1	22	—	—
Saudi Arabia	12	595	—	—
Other	(⁰)	16	(⁰)	6
Total	13	633	(⁰)	6
Africa:				
Congo	1	144	—	—
Gabon	5	90	—	—

See footnotes at end of table.

TABLE 8—Continued
**U.S. EXPORTS OF CONSTRUCTION SAND AND GRAVEL IN 1991,
 BY COUNTRY**

(Thousand tons and thousand dollars)

Country	Sand		Gravel	
	Quantity	F.a.s. value ¹	Quantity	F.a.s. value ¹
Nigeria	1	75	—	—
Other	(²)	82	—	—
Total ⁴	8	391	—	—
Grand total	439	13,001	700	6,043

¹Value of material at U.S. port of export; based on transaction price, including all charges incurred in placing material alongside ship.

²Less than 1/2 unit.

³Includes Anguilla, Antigua and Barbuda, Cayman Islands, Costa Rica, Guadeloupe, Honduras, Martinique, and Turks and Caicos Island.

⁴Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 9
**U.S. IMPORTS FOR CONSUMPTION OF CONSTRUCTION SAND AND
 GRAVEL, BY COUNTRY**

(Thousand short tons and thousand dollars)

Country	1990		1991	
	Quantity	C.i.f. value ¹	Quantity	C.i.f. value ¹
Antigua and Barbuda	130	2,083	92	61,178
Australia	130	5,945	29	1,773
Bahamas	338	789	269	1,075
Barbados	8	103	40	332
Bermuda	1	11	—	—
British Virgin Islands	4	64	4	85
Canada	983	5,771	955	6,543
Dominica	6	50	12	59
Dominican Republic	1	24	—	—
Germany, Federal Republic of	7	4,875	8	2,790
Japan	43	491	33	538
Mexico	3	367	5	611
Norway	76	1,102	13	591
South Africa, Republic of	\$1.00	210	—	—
Taiwan	\$7.00	67	(²)	15
Turks and Caicos Islands	1	11	—	—
United Kingdom	3	429	1	552
Venezuela	\$1.00	8	—	—
Other ³	1	511	4	496
Total ⁴	1,742	22,912	1,465	16,638

¹Value of material at U.S. port of entry; based on purchase price and includes all charges (except U.S. import duties) in bringing material from foreign country to alongside carrier.

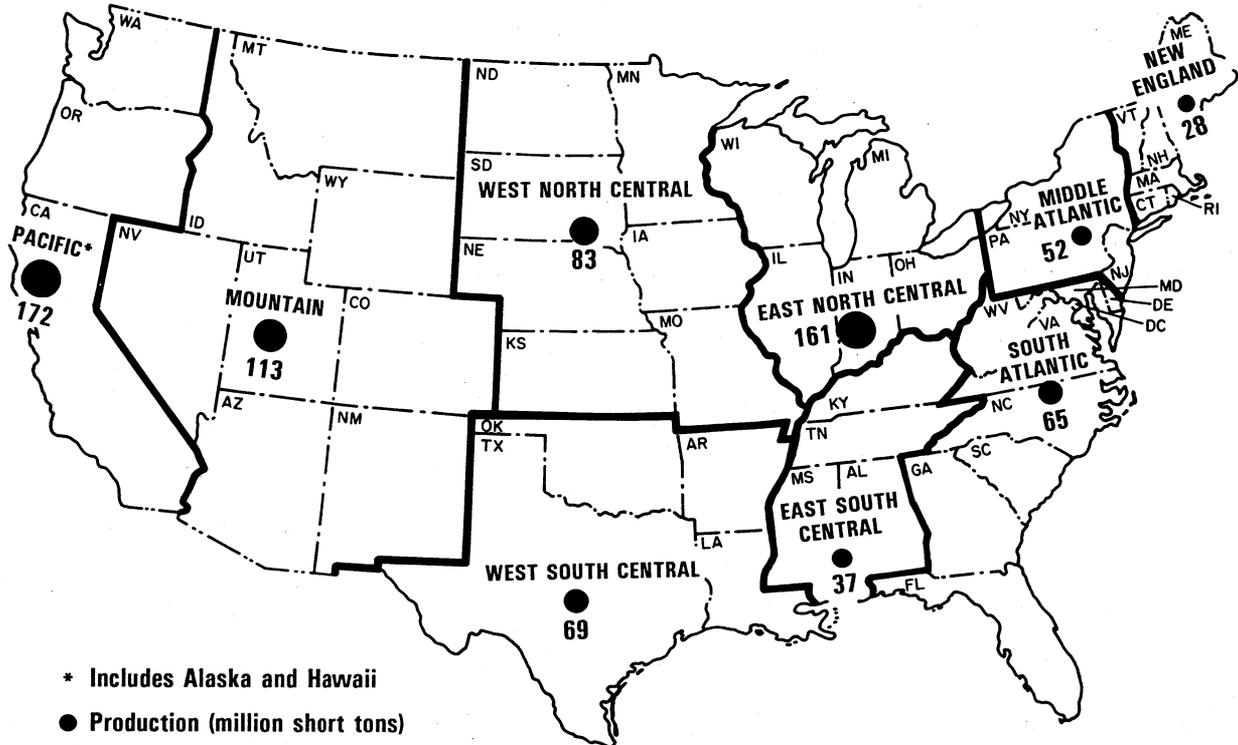
²Less than 1/2 unit.

³Includes Austria, Bangladesh, Brazil, China, France, Haiti, Hong Kong, India, Indonesia, Italy, Luxembourg, Madagascar, Mali, the Netherlands, the Netherlands Antilles, Papua New Guinea, the Philippines, Singapore, Spain, Sri Lanka (Ceylon), Sweden, Tanzania, the U.S.S.R., and the United Arab Emirates.

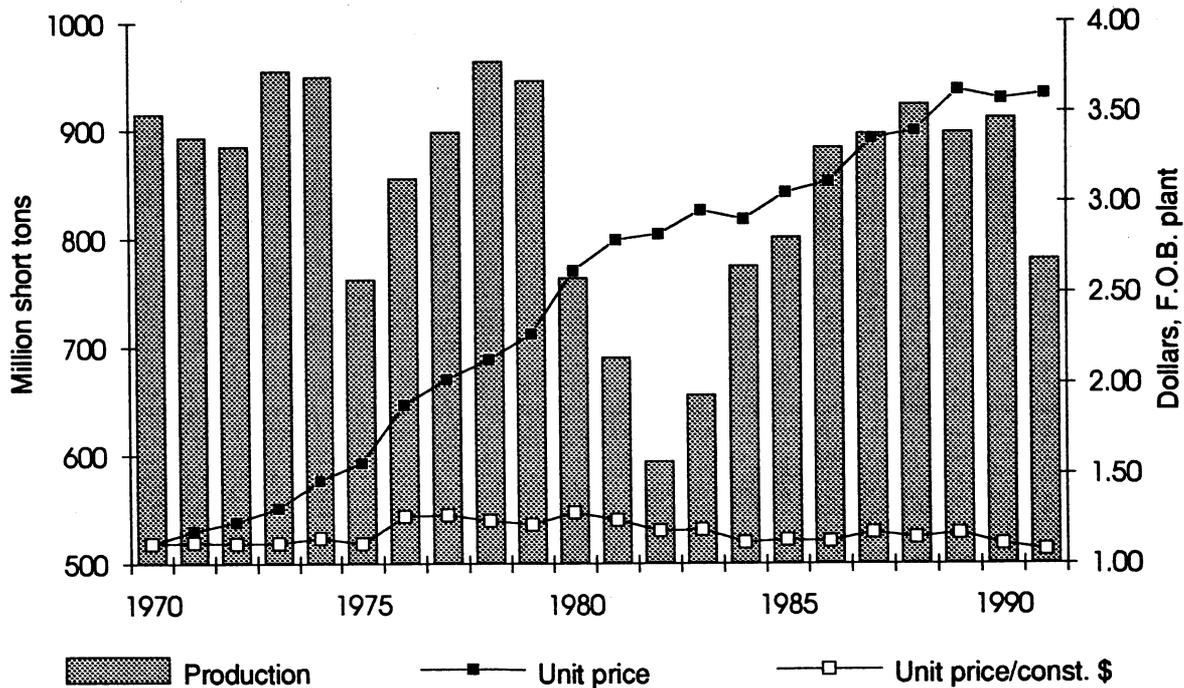
⁴Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

**FIGURE 1
PRODUCTION OF CONSTRUCTION SAND AND GRAVEL IN THE UNITED STATES IN 1991, BY GEOGRAPHIC REGION**



**FIGURE 2
PRODUCTION AND UNIT PRICE IN ACTUAL AND 1970 CONSTANT DOLLARS OF CONSTRUCTION SAND AND GRAVEL IN THE UNITED STATES**



INDUSTRIAL SAND AND GRAVEL

By Wallace P. Bolen

Mr. Bolen, a physical scientist, has been the commodity specialist for industrial sand and gravel since October 1988. Domestic survey data were prepared by Christopher H. Lindsay, statistical assistant; and the international production table was prepared by Ronald Hatch, international data assistant.

Probably no other nonmetallic mineral has more diversified uses than silica (industrial) sand, mainly because of its common occurrence around the world and its distinctive physical characteristics, including hardness, resistance to high temperature and chemical action, and relatively low price. Silica sand is the major component of common glasses, foundry molding and cores, abrasive blast sand, and hydraulic fracturing sand. Industrial sand and gravel is also important in ceramics, chemicals, and fillers for rubber and plastics, and also is utilized in golf courses, as a flux in smelting and chemical production, as filter media, and in many other uses.

DOMESTIC DATA COVERAGE

Production of industrial sand and gravel in 1991 decreased to 25.6 million short tons, about 10% less than 1990's production. Production decreased for the second year in a row, to its lowest level since 25.3 million tons was produced in 1967. During 1991, the following silica markets saw decreases in consumption: glass containers, fiberglass, foundry sand, blast sand, chemicals, and hydraulic fracturing sand (frac sand).

Exports of silica sand and gravel increased about 42% in quantity, but the average value per ton, compared with that of 1990, decreased 10%. Imports of industrial sand and gravel increased about 25% in quantity, but the associated value decreased 70%. Domestic apparent consumption of industrial sand and gravel in 1991 was 24.1 million short tons, a decrease of almost 12% compared with that of 1990.

Domestic production data for industrial sand and gravel were developed by the U.S. Bureau of Mines from voluntary surveys of U.S. producers. Of the 152 industrial sand and gravel operations surveyed, 119 (78%) reported to the U.S. Bureau of Mines. Their combined production represented about 86% of the U.S. total published in table 1. The production of nonrespondents was estimated mostly using employment data. Of the 152 operations, 148 (97%) were active and 4 idle. (See table 1.)

BACKGROUND

One of the first industries to use silica sand was the glass industry. At least 4,000 years ago, long before iron was smelted, glassmaking was already a known craft. Although the place and date of the first manufactured glass are not known, the oldest known specimens of glass are from Babylon (ca. 2600 B.C.) and from Egypt (ca. 2500 B.C.), where the industry was well established by about 1500 B.C. Many varieties of glass were known during Roman times. Little is known of the glassmaking methods used in Europe from the fall of Rome until the 10th century, when stained glass was produced in Venice. After this, Venice remained the leader in fine glassware for the next four or five centuries. In the 17th century, a process for casting glass was invented in France, and later, England began to make flint glass, marking the beginning of modern glass technology.

Glassmaking was apparently the first industry to be transplanted from Europe to North America, first to Mexico and

later to the British colonies. The first manufacturing establishment in what is now the United States was a glass factory at Jamestown, VA, built in 1608. The 1885 edition of "Mineral Resources of the United States," the predecessor of today's U.S. Bureau of Mines "Minerals Yearbook," reported a total of 317,000 tons of silica sand produced in 1884 in the United States, under "Glass Materials." In 1991, a total of 25.6 million tons of silica sand was produced in the United States for a variety of uses, of which 11.2 million tons was for glassmaking. Today, glass has become an invaluable product with a multitude of forms and applications.

Metals casting was probably the second industry that used silica sand. Today, the casting industry provides vital components for most modern manufacturing industries. The number of industries using silica sand is growing constantly, as are the products made by using silica sand.

Definitions, Grades, and Specifications

Sand is defined throughout the industry and by the American Society for Testing and Materials (ASTM) as granular rock particles that pass through a No. 4 mesh (0.187-inch) U.S. standard sieve, are retained on a No. 200 mesh (0.0029-inch) sieve, and are the result of natural disintegration or comminution of cemented rock. Industrial sand or silica sand is the term used by the industry for sands that have a very high percentage of silicon dioxide (SiO₂) and are essential materials in glass manufacture, in ferrous and nonferrous foundry operations, in

certain chemical and metallurgical processes, for hydraulic fracturing of oil and gas deposits, and in many manufactured products as fillers or extenders.

Most industrial sands have been named for their specific uses; for example, glass, foundry, abrasive, filler, and hydraulic fracturing sands. Almost invariably, these sands, in addition to being high in silica, consist mostly of quartz grains.

Products for Trade and Industry

Silica sand had a wide range of uses in a significant number of industries, the most important being glass and foundry. Other uses were metallurgical and as abrasives, as fillers, for filtration, and for hydraulic fracturing of rock formations to improve recovery in oil wells.

Glass sand was used as a main constituent for manufacturing glass containers, flat glass, safety glass, pressed and blown glass, fiberglass, and a wide variety of specialty glasses such as optical glass and industrial glass.

Glass sand had to meet rigid specifications with respect to purity and silica content, depending on the kind of glass being manufactured. Only a very small amount of iron oxide and chromium compounds could be tolerated, and a high percentage of aluminum, calcium, or magnesium oxides was undesirable. The standards of the American Ceramic Society for glass sand indicated that all grains should pass through a No. 20 mesh screen, between 40% and 60% should be retained on a No. 60 screen, between 10% and 20% on a No. 80 screen, and not more than 5% should pass a No. 100 screen. Sand for first-quality optical glass should contain 99.8% SiO₂ and a maximum of 0.1% aluminum oxide (Al₂O₃) and 0.02% iron oxide (Fe₂O₃). Third-quality flint glass could contain only 95% SiO₂ and as high as 4% Al₂O₃. Only in the low-quality amber glass was the content of Fe₂O₃ permitted to reach 1%.

Most glass manufacturers established their own specifications for the physical size and chemical purity of the raw

materials that have to be met by the suppliers of glass sand. Recently, glass manufacturers showed an increased interest in finer glass sands because processing of smaller particles required lower temperatures and, therefore, reduced the consumption of energy.

Foundry sands included molding sand and core sand that were used for casting iron-, aluminum-, and copper-base alloys. Required properties included cohesiveness sufficient to hold together the mold or core when moist, which is achieved by a bonding agent; refractoriness to withstand the high temperature of the molten metal; strength to resist the weight of the metal; permeability to release vapors and gases generated during cooling of the metal; and proper texture and composition to produce a smooth casting that will not react with the metal. Most metals were cast in "green sand," which is a mixture of silica and clay, although to a lesser extent, resins or oils were also used as a bonding agent instead of clays. In the case of naturally bonded foundry sands, the amount of clay minerals present affected their usefulness. Standard tests and specifications for foundry sands were published by the American Foundrymen's Society.¹

Refractory sands were used in the manufacture of silica brick and tile, quartzite (gannister) being the commonly used raw material. Required properties were "the capability of maintaining the desired degree of chemical and physical identity at high temperatures" and resistance to abrasion, impact, thermal shock, and high level of load. Refractory silica materials were classified based on their general composition and on their distinctive properties. Standard classifications and specifications for silica refractory brick were published by the ASTM.²

Quartz sands, on the Knoop scale at 820, are quite hard and are one of the oldest abrasives known. Abrasive sands were quartz sands used in stone sawing, glass grinding, metal polishing, and sand blasting. No rigid specifications existed for these sands, but sound, clean, hard, and closely sized sand grains were required. Purity and grain-shape

specifications varied with the type of abrasive action and the requirements of the final product. An angular particle shape with sharp cutting edges was generally required.

Hydraulic fracturing sand was pumped into oil or natural gas wells as a sand-liquid mixture to break up petroleum-bearing formations and act as a propping agent, allowing oil or gas to move more freely toward the producing wells. Some of the major requirements for fracturing sands were spherical, well-rounded grains of clean, dried, and well-screened quartz sand, free of any materials such as feldspar, calcite, and clay. The most common size was 20/40 mesh; other sizes included 6/12, 8/16, 12/20, 40/70, and 70/140, but these sands represented only about 15% of the total sand used as proppant. "Recommended Practices for Testing Sand Used in Hydraulic Fracturing Operations," published by the American Petroleum Institute, was used as a guide by industry.³

Ground sand or silica flour has found wide industrial application as a filler in paint, plastics, rubber, ceramics, and a variety of other products. Mainly because of the diversity of its uses, no standard specifications exist for the silica flour used in most of these applications except grain size and chemical composition.

Silicon carbide, which was used as an abrasive, for refractory uses, and in specialty ceramics, was produced by the reaction of silica sand (60%) and coke (40%) at elevated temperatures up to 2,400° C.

Metallurgical sand was used as a fluxing agent for basic oxides in various smelting operations and as a source of silicon in ferrosilicon manufacture. The ferrosilicon was a steel alloying additive. Filter sand was used extensively in filtering water for municipal and industrial use and swimming pools and in sewage treatment plants. Engine sand was used in locomotive haulage to improve traction. Other sands were used in special cements, in manufacturing silica brick and tiles for furnace linings and beds, for coal washing, and in manufacturing pottery. Industrial sand

was also used for chemical production, golf courses (both in traps and in green construction), and building products. Industrial gravel was used as the source material in the production of silicon and ferrosilicon and as a flux for the production of copper, nickel, and elemental phosphorus. Some gravel was also used as filtration media, mainly in municipal water treatment facilities.

Industry Structure

In 1991, 77 U.S. companies with 148 active operations produced silica sand and gravel. The individual industrial sand and gravel operations ranged in size from those producing about 1 million tons annually to those reporting less than 10,000 tons per year. Most of the production came from large operations that were mostly owned or operated by a small number of companies. In the past 10 to 15 years, there was a gradual trend toward larger operations, mostly because small plants were becoming less economical. The viability of small operations was dependent on demand in local markets, mining conditions, and the degree of processing required to supply the final product.

During the past 10 years, changes within the structure of the industrial sand industry occurred, primarily caused by mergers and acquisitions, some resulting from an influx of foreign capital, mostly from Europe.

Geology-Resources

U.S. resources of industrial sand and gravel were expected to be sufficient to meet domestic demand in the foreseeable future, although their geographic distribution and quality often did not match market requirements. The availability of these reserves was controlled to a significant degree by land use and/or environmental constraints. Reserves of industrial sand and gravel owned or controlled by domestic producers were estimated to total about 3 to 4 billion tons.

Although silica reserve data for the rest of the world were not available, it

could be assumed, on the basis of geologic evidence, that world reserves were sufficient to meet demand, even if not always at the locations where needed.

Industrial sand or silica sand was produced in the United States from a variety of geological formations ranging in age from late Precambrian to mid-Tertiary. About 70 stratigraphic units were known as having an economic potential for this industry. Lithologically, these deposits ranged from quartzites, sandstones with different degrees of cementation, quartz conglomerates, chert deposits, and quartz pegmatites to terrace sands and gravels, and dune sands. Most of the high-quality industrial sand was produced from a few geological formations in the Eastern United States. Oriskany sandstone, or more precisely the Ridgeley formation of Early Devonian age, was one important source of silica sand. It extended from New York State to southern Virginia and eastern Ohio, but was being mined only in central Pennsylvania, northwestern Maryland, and northern West Virginia, where the formation was thick enough to be of commercial value. It was a hard, white orthoquartzite with medium to fine, angular and subangular, and well-sorted grains. The St. Peter sandstone of Middle Ordovician age, extending from Wisconsin and Minnesota through Iowa, Illinois, and east-central Missouri, was another major source of industrial sand. The best known center of production of silica sand from this formation was the Ottawa district of La Salle County, IL, where it was known as "Ottawa sand," and to a lesser degree in southern Wisconsin and east-central Missouri. It was a soft and poorly cemented high-purity orthoquartzite with coarse, rounded grains. The weak cement holding the silica grains together was mostly a light-colored clay.

In addition to the two formations just mentioned, the most important sources of industrial sand in the United States, numerous other deposits were also being mined for silica sand in different parts of the country. Included are the Jordan sandstone of Upper Cambrian age in Minnesota and Wisconsin, a primary

source of hydraulic fracturing sand; the Raritan formation of Upper Cretaceous age in central New Jersey and the Cohansey sand of probable Miocene age in southern New Jersey; and the Tuscarora quartzite of Lower Silurian age in Pennsylvania and Virginia used for the manufacture of refractory bricks. Other deposits are the Sylvania sandstone of Devonian age in the Detroit area; the Oil Creek and McLish formations of Lower Ordovician age in Oklahoma, a southwestward extension of the St. Peter sandstone; and the Hickory sandstone of Cambrian age in central Texas that produced mostly hydraulic fracturing sand.

In the West, the most important sources of industrial sand were the Ione formation of Eocene age in northern California, the Silverado (Paleocene) and Tejon (Eocene) formations in southern California, and the Eureka quartzite of Middle Ordovician age in central California.

Approximately two-thirds of the U.S. industrial sand and gravel was produced east of the Mississippi River, especially in the industrialized areas of the East North Central, South Atlantic, and Middle Atlantic regions. Of the top five producing States that accounted for about 45% of 1991 production, three—Illinois, Michigan, and New Jersey—were in the East and the other two—California and Texas—were in the West. The concentration of the industrial sand operations in the eastern part of the United States resulted from the existence of high-quality geologic deposits close to the major consuming industries, glass and foundry. In the south and west, demand from the oil and gas industry in the Louisiana, Oklahoma, and Texas area has sustained the growth of industrial sand operations in Texas. California production remained large owing to demands from local industry, particularly the glass container industry, and the distance of California from the traditional production areas in the Midwest.

Technology

Exploration.—A large number of geologic formations with economic potential as a source of industrial sand have been mapped and described in the literature over many years and were, therefore, well known. Consequently, detailed exploration and development work for new industrial sand operations was expected to occur on some of these formations. The qualities of a silica deposit necessary for a viable operation should include proper particle size, chemical composition, degree of cementation, and deposit uniformity. Also, the nature and amount of waste material and the economic feasibility of its removal and possible use or disposal should be studied. The evaluation of the new deposit should also include an environmental impact study as required by most local or State agencies before authorizing a new mining operation.

If the raw material should prove to meet the requirements and adequate reserves are demonstrated, the development stage of the operation could be started. Economic feasibility and marketing studies should be performed by analyzing all factors important for any such mining operations. Included are the availability of power and water supply, mining and processing costs and requirements, and the condition of nearby roads and highways. Other factors include the proximity of rail haulage; the cost of compliance with local, State, and Federal regulations; and the proximity and density of local population as well as its attitude toward such a project.

Mining.—Most industrial sand was mined from open quarries, but a few underground operations existed, mostly because of an exceptionally thick overburden or environmental limitations. Surface mining methods and equipment varied with the type of the geologic formation, size and configuration of the deposit, production capacity, estimated life of the operation, and location of the deposit with respect to urban centers. The mining methods depended primarily

on the degree of cementation of the rock, although most open pit mining operations included site clearing and removal of the overburden; mining of the silica rock or sand; processing of the material, including crushing, screening, and classification; and reclamation of the extraction area. Unconsolidated sands, such as the Cohansey of New Jersey, below the ground water level were dredged. Much of the St. Peter sandstone was first loosened by light blasting and then washed down by hydraulic jets or "monitors" into sumps, from which it was pumped to the processing plants. Harder rock such as the Oriskany sandstone required blasting and primary and secondary crushing before it could be processed.

Processing.—Processing of mined silica sand required specialized operations that varied considerably with the nature of the deposit and the physical and chemical requirements of the desired product. Depending on the degree of cementation, several stages of crushing were necessary to achieve the desired size reduction. Gyratory crushers, jaw crushers, impact mills, or roll crushers were used as primary or secondary crushers, and smooth rolls, media mills, autogenous mills, high-speed hammer mills, or fluid energy jet mills were used for grinding the product down to 50 microns and finer. Dry or wet screening was used to separate particles of sizes down to about 150 microns, and wet or air classifiers processed particles from 250 microns into the submicron range. Vibratory screens and gyratory screens, in addition to mechanical, hydraulic, or air classifiers, were used, depending on the size distribution required.

Research for the silica mining industry related not only to new methods that increased output and reduced production costs but also to health and safety problems as well as exploration, land management, and reclamation. Equipment manufacturers and some Government agencies were constantly working on improving exploration, mining, and processing plant technology.

Significant technological developments instrumental in maintaining adequate production at relatively stable real costs were mostly in the processing plant technology. The use of computerized systems in plant operation and quality control increased; this, along with improved mining and processing equipment, permitted the recovery of salable fractions that were previously considered uneconomical.

Recycling.—Recycling of silica sands was limited to some foundry sands, particularly those used for making cores and molds with no-bake resin-bonded sands, some abrasive and airblasting sands, and, increasingly, post consumer glass and scrap glass that substitutes for glass sand. Most glass recycling was restricted to container glass, with green and amber being consumed at a higher rate than flint because it was more difficult to use in the batch mix. As the level of glass used increases, so does the level of quality required. Contamination of cullet by ceramics and nonmagnetic materials was an increasing concern. International trends toward increased recycling of glass and foundries sands and innovative ideas on recycling other materials should influence greater recycling of silica products.

Byproducts and Coproducts

Small amounts of gold and silver were recovered occasionally as a byproduct or coproduct from some unconsolidated silica sand deposits. Also, during the processing of some silica resources, other minerals, including clays, feldspars, mica, and quartz crystals, were produced as byproducts and coproducts.

Economic Factors

Silica sand deposits are nonrenewable resources. New mining methods combined with advances in mineral processing that were introduced during the past decade have increased the number of silica deposits that can be commercially developed.

The industrial sand industry was very competitive, largely because silica sand is a relatively abundant mineral, with supply usually exceeding demand. The delivered price of the product, in addition to quality, was a very important element in any major transaction. The producer with an operation closest to the market had a significant advantage over competitors. Combining sophisticated (and therefore expensive) processing equipment backed by technical knowledge and solid sales expertise was important. For this reason, only a small number of large companies were able to compete successfully and succeed in the silica sand business and supply a wide variety of products. Smaller, less efficient operations became uneconomical as operating costs, as well as costs associated with meeting various Federal, State, and local regulations, continued to increase. The only alternatives they had were to either limit the range of products they supplied to close markets or go out of business.

Prices.—As a result of rapidly rising costs of labor, energy, and mining and processing equipment, 1991 constant dollar prices of industrial sand rose steadily between 1973 to 1983. From 1985 to 1991, 1991 constant dollar prices fluctuated in the 15.25 to 16.25 range owing to decreased demand and tight competition in some markets. Prices should be expected to continue to fluctuate, although they should slowly rise as a result of the cost of compliance with more stringent environmental, land use, and safety regulations.

Costs.—Production costs for silica sand were determined to a large extent by the cost of labor, equipment, energy supply, water availability, and the additional burden of compliance with environmental and safety regulations. Production costs varied widely depending on the nature of the geologic deposit, the geographic location, and the type and number of products produced. Profits were relatively small for most producers, total

production costs being close to the f.o.b. selling price per ton.

Tariffs.—There has been no tariff on imported silica sand containing 95% or more SiO₂ and not more than 0.6% iron oxide from most favored nations since January 1, 1987. For all other countries, the tariff for imported silica sand remains \$1.94 per long ton.

Depletion Provisions.—The depletion allowance for industrial sand and gravel was 14%.

Operating Factors

Environmental Requirements.—Major environmental considerations that had to be dealt with in mining and processing of industrial sand and gravel were emission of particulate matter into the air, discharge of processing water, and noise abatement. Air pollution constituted a major problem in the processing plants, especially in the drying and packaging stages of finer products such as silica flour, silicosis being the major disease that can be contracted as a result of long-term exposure to silica dust. Because of the high cost of compliance with the environmental regulations designed to reduce this health hazard and possible long-term liabilities associated with it, some companies were no longer producing silica flour or did not plan to produce it in the future. Both wet and dry methods of dust control were used. The most important water pollutant was clay in suspension as a result of washing and screening silica sand. Because of the large quantities of water used to process silica sands and the need of compliance with stringent regulations, the treatment of discharge water by the sand producer was expected to require increasingly sophisticated and expensive processing methods. Significant progress was made in reducing noise pollution, both inside and outside of the operations, including noise and vibration produced by blasting and movement of heavy trucks.

Sand producers had to obtain mining permits from the appropriate

governmental agency, which sometimes also required an Environmental Impact Statement (EIS) and a reclamation plan that met its guidelines or regulations. More and more emphasis was being put by local communities on improving the overall appearance of the operating mines as well as on land reclamation after mining was completed. At the same time, industry and the communities had to recognize the time and costs required to protect the environment and the importance of agreeing on fair and realistic environmental standards. Many States, counties, and towns had zoning laws that regulated land use.

Most of the active silica sand quarries as well as the known deposits were on private land, which was either owned or leased on a long-term basis by the producers. These deposits contained high-quality silica sand and were in the best locations with respect to markets. Unlike the construction sand and gravel industry, the industrial sand industry was usually not significantly affected by increasing land values near populated areas.

Transportation.—Transportation costs for silica sand were often equal or considerably greater than the cost of the product at the processing plant. Because of the large variety and number of consumers of silica sand, long distance haulage was not uncommon. In 1991, the largest tonnage, 56% of all industrial sand, was shipped by truck because most users require a versatile and rapid delivery system. Substantial quantities, 40% of the total, were also shipped by rail, especially when large volumes were sent long distances. The remaining tonnage was shipped by barge or used at the mine.

ANNUAL REVIEW

Production

The Midwest (East and West North Central regions) continued to lead the Nation in production, with about 42% of the 25.6 million tons produced in the United States, followed by the South

(South Atlantic, East and West South Central regions) with about 36% and the West (Pacific and Mountain regions) with 14%. (See table 2 and figure 1.)

Based on the 1990 census estimations on population, 1991 U.S. per capita industrial sand and gravel production was 0.10 ton. Per capita production by major geographic region was 0.18 ton in the Midwest, 0.11 ton in the South, 0.07 ton in the West, and 0.05 ton in the Northeast.

The five leading States in the production of industrial sand and gravel, in descending order of volume, were Illinois, California, Michigan, New Jersey, and Texas. Their combined production represented 45% of the national total. Significant changes within the five major producing States included Texas, where production decreased almost 16%, and California, where production decreased by more than 14%. Production decreased in almost every State except in a few instances where production rose by a small percentage. (See tables 3, 4, and 5.)

The U.S. Bureau of Mines canvassed 77 producers of industrial sand and gravel with 148 active operations. About 74% of the industrial sand and gravel was produced by 44 operations, each with an annual production of more than 200,000 tons. The 10 leading producers of industrial sand and gravel were, in descending order of tonnage, Unimin Corp., U.S. Silica Co., Fairmount Minerals Ltd., The Morie Co. Inc., Oglebay Norton Co., Badger Mining Corp., Simplot Industries Inc., Construction Aggregates Corp., Owens-Illinois Inc., and WHIBCO Inc. Their combined production, from 63 operations, represented 72% of the U.S. total.

Consolidation of silica companies continued in 1991 as Fairmount Minerals acquired some of Manley Brothers of Indiana's operations from Hepworth Minerals and Chemicals Ltd. of the United Kingdom. The remaining Manley Brothers operation, in Illinois, was taken over by the management, which planned to maintain the Manley Brothers of Indiana name. The Securities Exchange

Commission (SEC) ruled that Fairmount Minerals would not be allowed to purchase the entire Manley operation. The SEC determined the planned takeover was anticompetitive because of the change in market share distribution. With this purchase, Fairmount Minerals strengthens its hold as the third largest producer of industrial sand and gravel in the United States. Fairmount takes over mines and mills in two locations in Michigan as well as some other Manley facilities.

Spruce Pine Sand and Gravel, Franklin County, AL, discontinued sales of industrial gravel owing to the closure of elemental phosphorus plants at Olin and Occidental Chemicals' plants in Tennessee. Other producers also saw halts or decreases in gravel sales for elemental phosphorus production.

Ideal Basic Industries Inc. sold its Hempstead County, AR, operation to Holnam, Inc., a subsidiary of Financiere Glaris Ltd.

Salt Lake Valley Sand and Gravel temporarily shut down its facility for the production of abrasive blast sand.

Feldspar Corp. sold its ultrahigh-purity silica plant at Spruce Pine, NC, to Unimin Corp. Unimin is now the sole U.S. producer of ultrahigh-purity silica (less than 30 parts per million total impurities).

Consumption and Uses

Sand and gravel production reported by producers to the U.S. Bureau of Mines was actually material used by the companies or sold to their customers. Stockpiled material was not reported until consumed or sold.

Of the 25.6 million tons of industrial sand and gravel sold or used, 44% was consumed as glassmaking sand and 22% as foundry sand. Other important uses were abrasive sand (7%) and frac sand (5%). Because some producers did not report a breakdown by end use, their total production as well as the estimated production for nonrespondents were included in "Other uses, unspecified," which represented about 4% of the U.S. total.

On the regional level, more than one-third of the glassmaking sand was

produced in the South (40%), followed by the Midwest (30%) and the West (17%). Three-fourths of the foundry sand was produced in the Midwest (74%). About three-fourths of the hydraulic fracturing sand was produced in the Midwest (73%), and the majority of the abrasive sand was produced in the South (65%). (See table 6 and figure 2.)

Northeast.—Cumberland County, NJ, continued to be the largest source for the glass and foundry sand markets in the region. Unimin, U.S. Silica, Morie, and WHIBCO Inc., all of which operated plants in the county, were among the largest producers of sand for these markets. U.S. Silica's plant in Huntingdon County, PA, also produced significant amounts of sand for the glass market. Morie's plant in Cumberland County and New Jersey Pulverizing Co.'s plant in Ocean County, NJ, produced a major percentage of the abrasive blast sand in the region.

Midwest.—Unimin's plants in LaSalle and Ogle Counties, IL; LeSueur and Scott Counties, MN; and Columbia County, WI, were among the leaders in producing sand for the glass, foundry, and frac sand markets. Fairmount Minerals, with operations in Berrien and Van Buren Counties, MI; Geauga County, OH; and La Salle County, IL, was a major producer of sand for the blast, foundry, frac, and glass sand markets in the region. U.S. Silica's plant in La Salle County, IL, and Badger Mining's plant in Jackson County, WI, were large producers for the glass and frac sand markets, respectively. Construction Aggregates Corp. in Ottawa County, MI, and U.S. Silica in LaSalle County, IL, were major producers of foundry sand in the region. Nugent Sand Co. Inc., in Muskegon County, MI, Badger Mining in Green Lake County, WI, and Sargent Sand Co. in Wexford County, MI, were also large producers for the foundry industry.

South.—Unimin and U.S. Silica Co. were two of the largest producers of sand

for the glass and foundry markets. Unimin's major plants were in Frederick County, VA; Richmond County, NC; Pontotoc County, OK; and Izard County, AR. U.S. Silica's Bullock County, AL; Morgan County, WV; Johnston County, OK, and Limestone County, TX, operations were the major contributors for these markets. Morie's Tuscaloosa County, AL, and Marion County, GA, plants were large producers of blast, foundry, and glass sand. Huey Stockstill Inc., Pearl River County, MS, Mid-State Sand and Gravel Co., Baywood and Baggett Parishes, LA, Pioneer Concrete of Texas Inc., Colorado and Liberty Counties, TX, Oglebay Norton's Texas Mining Co., McCulloch County, TX, and Specialty Sand Co., Colorado, Harris, and Newton Counties, TX, were large producers of blasting sand. W.R. Bonsal and Co., Anson County, NC, produced a large percentage of the industrial gravel used in the production of silicon and ferrosilicon. Oglebay Norton's Texas Mining Co. and Vulcan Materials Co., both in McCulloch County, TX, were the largest producers of frac sand in the region.

West.—Corona Industrial Sand Co., Owens-Illinois, Simplot Industries, and Unimin were the four largest producers of glass sand in the region, with major operations in Riverside County, CA, Amador County, CA, Clark County, NV, and Contra Costa County, CA, respectively. Lane Mountain Silica, Stevens County, WA, and Lone Star Industries Inc., Monterey County, CA, were the major suppliers for the sand blasting industry in the region. Simplot Industries also supplied a large portion of the foundry sand consumed.

Transportation

Of the total industrial sand and gravel produced, 56% was transported by truck from the plant to the site of first sale or use, unchanged from that of 1990; 40% was transported by rail, also unchanged from that of 1990; 3% by waterway; and only 1% was not transported. Because most of the producers did not report

shipping distances or cost per ton per mile, no transportation cost data were available. (See table 7.)

Prices

Compared with that of 1990, the average value, f.o.b. plant, of U.S. industrial sand and gravel decreased slightly to \$15.25 per ton. Average unit values for industrial sand and industrial gravel were \$15.39 and \$12.18 per ton, respectively. Nationally, industrial sand used as fillers for rubber, paint, and putty, etc., had the highest value per ton (\$69.77), followed by silica flour, (\$36.50), silica sand used in ceramics (\$36.28), fiberglass (ground) (\$35.70), scouring cleansers (\$29.84), and frac sand (\$27.10).

Unit values for different uses of industrial sand and gravel generally changed little from 1990 to 1991 even though total tonnage sold and used changed substantially. Despite the decreased sales for most uses, some uses underwent an increase in average value. These included sand for flat and specialty glasses, ground sand for fiberglass, foundry, filtration, frac, and sand used in roofing granules and fillers.

The average value per ton of industrial sand and gravel was highest in the West (\$17.68), followed by the Northeast (\$15.55), the South (\$15.51), and the Midwest (\$14.15). Glass sand average value per ton varied markedly, from \$17.27 in the West to \$9.74 in the Midwest. Tighter supplies and higher production costs in the West increased the cost of sand and gravel in this region.

Foreign Trade

Exports.—Exports of industrial sand, compared with those of 1990, increased 42% to 1,637,000 tons, and the value increased 27% to \$106.7 million. Of this, 73% went to Canada, 13% went to Mexico, 3% went to Japan, and the remainder went to numerous other countries throughout the world.

Imports.—Compared with those of 1990, imports for consumption of industrial sand increased 25% to 91,000 tons valued at \$932,000. More than 98% of this was lower value silica from the Federal Republic of Germany. Small amounts of specially prepared silica sand from Australia, Belgium, Canada, France, Italy, Japan, Mexico, Sweden, Switzerland, and the United Kingdom sold for very high values per ton. (See tables 8 and 9.)

World Review

World production of industrial sand and gravel, based on information usually provided by foreign Governments, was estimated to be 121.7 million short tons, a decrease of 6% from that of 1990. The Netherlands was the leading producer, followed by, in descending order, the United States, Argentina, the Federal Republic of Germany, and Japan. Most countries in the world had some production and consumption of industrial sand and gravel because of its basic uses in glass and foundries. However, because of variation in descriptions and usage for silica sand and gravel, it was difficult to get reliable information. Beyond those countries listed, many other countries were believed to have had some type of silica production and consumption. (See table 10.)

Current Research

Advances continued through 1991 into research involving glasses, glass fibers, silicon carbide, silicon nitride, silica fabrics, and fiber optics.

Corning Inc. reported that global demand for optical fiber expanded by 30% during 1990. Corning continued R&D in fiber-optic components that split, combine, or vary the intensity of optical signals. Corning urged Congress to remove barriers to competition that are inhibiting deployment of optical fiber to schools, homes, and hospitals as well as business.⁴

A new development involving rare-earth fluoride glasses found that

lanthanide-doped fluoride fibers have a unique guiding configuration that allows the materials to be used as optical amplifiers and fiber lasers.⁵

Researchers reported a breakthrough in optical signal amplification that could slash the cost of future fiber-optic systems. The new amplifiers use special fluoride glass fibers treated with rare-earth praseodymium and boosted signal strength more than 1,000 times.⁶

A leaching process reportedly converts knitted and woven glass fabrics to silica, increasing the fabrics maximum operating temperature. The temperature-resistant fabrics are used for high-temperature insulation, welding protection, and metal filtration.⁷

Toyota Motors continues research into lightweighting to improve mileage and reduce air and noise pollution. Steel was replaced in seats by fiberglass springs, which improved passenger comfort while cutting the weight of the vehicles.⁸

A particulate silicon carbide metal matrix composite was used in the manufacture of a bicycle frame. The tubing used in the frame has a specific strength and stiffness higher than any other metallic frame material.⁹

Kyocera of Japan announced a new ceramic engine parts pilot plant to be built in Vancouver, WA. A spokesman said that the company would focus on components made from sintered silicon nitride ceramic. The material, compared to alumina ceramics, was claimed to be much less susceptible to thermal shock and able to maintain its strength at higher temperatures.¹⁰

Chemists at the University of California at Berkeley have blended polymers and glass at near-molecular level. The result, they say, was a composite one-half the weight of glass, but far stronger and nearly indistinguishable in clarity and resistance to scratches and corrosion.¹¹

The construction industry is taking its first tentative steps toward what may one day be the widespread use of recycled, crushed, mixed-color glass as an aggregate fill around subsoil culverts, pipes, and drains. Increased use of

recycled glass in this manner would increase use of virgin silica sand.¹²

In health-related matters, 3M Corp. announced a new respirator, 8825, which is believed to be the first dust, mist, and metal fume respirator to meet the requirements of TM14 Part 9.1, FFP2 Solid and Liquid. 3M stressed function and comfort in the design of this respirator, which is said to offer protection that exceeds exposure limits in most countries.¹³

In a related area, the U.S. Bureau of Mines recently carried out two studies that evaluated workers' dust exposures in automated-pallet-loading processes. The first study involved a dust control system using a push-pull ventilation technique that reduced dust exposure 76%. The second study evaluated different commercial automated-pallet-loading systems. A review was published in Mining Engineering Magazine.¹⁴

OUTLOOK

Demand

The forecast range of total U.S. demand in the year 2000 was expected to be 28 to 39 million short tons for industrial sand and gravel. Probable demand was expected to be about 34 million tons, which corresponded with an average annual growth rate of 3.4%. All forecasts were based on previous performances for this commodity within various end uses and contingency factors considered relevant to the future of the commodity. (See tables 11, 12, and 13.)

Glass Sand

Since 1987, annual demand for glass sand had fluctuated between 11.1 and 12.3 million tons. Sand consumed for container glass has decreased since 1987 mainly because some glass containers were being replaced by aluminum cans and plastic containers and also because the amount of glass being recycled was increasing. Additionally, many manufacturers of container glass were using thinner walls in glass containers, and this process had cut down the amount

of sand used. Also, a new thinner and lighter safety glass was used in automobiles, and its use was growing. As a result of these contingency factors, demand for glass sand was expected to grow slowly until the year 2000. Probable demand for glass sand for the year 2000 was forecast to be 13 million tons, with a range of 12 to 15 million tons. The probable forecast indicated an annual growth rate of 1.8%.

Foundry Sand

The probable forecast for foundry sand was expected to be 8.5 million tons, and the range was expected to be 7 to 10 million tons. The probable forecast indicated an average annual growth rate of 5.4%. The use of foundry sand was seen to be dependent mainly on automobile production. Recently, many foreign automakers have opened plants in the United States, and this should support growth in sales of foundry sand as a greater percentage of cars sold in the United States will also be made in this country.

Hydraulic Fracturing Sand

This end use declined greatly in 1991, sinking to less than 1.4 million tons. Although the amount of hydraulic fracturing sand used in each oil and gas well increased, drilling activity decreased. This occurred because of lower than hoped for prices for oil and gas attributed to the stabilization of world oil markets after the Gulf War. However, demand was expected to grow for this end use during the decade, partially due to increased exports of frac sand. Probable demand for hydraulic fracturing sand for the year 2000 was expected to be 2.3 million tons, with a range of 1.7 to 2.7 million tons. The probable forecast indicated an annual growth rate of 4%.

Adequacy of Supply

Domestic production was expected to continue to meet more than 99% of demand through the year 2000. Imports,

mostly from Australia and Canada, were expected to remain minor.

The United States was the second largest producer and consumer of silica sand among the market economy countries and was self-sufficient in this commodity. Most of it was produced in the eastern part of the United States, where the largest deposits and major markets are. A significant amount of silica sand was also produced in the West and Southwest, mostly in California and Texas.

Because the unit price of silica sand was relatively low, except for a few end uses that required a high degree of processing, the location of silica sand deposits in relation to the market was an important factor that may work for or against a sand producer. Consequently, a significant number of relatively small operations supplied local markets with a limited number of products.

The constant-dollar price of domestic silica sand had fluctuated since 1983 and was expected to continue fluctuating because of strong competition among producers for retention of dwindling markets.

Possible Supply-Demand Changes

Several factors could affect supply-demand relationships for silica sand. Further increases in the development of substitute materials for glass and cast metals could reduce demand for glass sand and foundry sand but would increase demand for silica flour, which is used as a filler in plastics, and for glass fibers, which are used in reinforced plastics. Also, increased efforts to reduce waste and increase recycling could hinder glass sand demand. However, with advances in high-technology materials, silica sand may see increased consumption for ceramics, fiber optics, and other silicon and glass compounds. Although developments could cause demand for silica sand to decrease, the total value of production could increase because of the increased unit value of the new specialized sands.

An increase in the price of oil on the international market would stimulate

domestic drilling and extraction from new and old oil deposits. This would increase demand for domestic hydraulic fracturing sand.

Concern over the use of silica as an abrasive due to health concerns and the imposition of stricter legislative and regulatory measures concerning silica exposure could decrease demands in many silica markets. Silica sand for use in the abrasive blast industry was being attacked as a health hazard as marketers of competing materials, including garnet, slags, and olivine, pushed the use of their "safer" abrasive medium.

Development of more efficient mining and processing methods are expected to continue. This will enhance development of lower grade silica sand deposits closer to markets but not presently mined. Such developments are expected to increase silica sand reserves.

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———. *Mold & Core Test Handbook*. 1st ed., 1978, Des Plaines, IL, 388 pp.

²American Society for Testing and Materials. *Standard Classification of Silica Refractory Brick*. C 416-70 in 1984 Annual Book of ASTM Standards: V. 15.01, Refractories, Manufactured Carbon and Graphite Products; Activated Carbon. Philadelphia, PA, 1984, p. 140.

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³American Petroleum Institute. *Recommended Practices for Testing Sand Used in Hydraulic Fracturing Operations*. 1983, 13 pp.

⁴Ceramic Industry (Solon, OH). *Corning Forecast Strong Optical Fiber Market*. V. 137, No. 1, July 1991, p. 16.

⁵———. *Fluoride Glasses Hold Commercial Promise as Fibers*. V. 137, No. 6, Nov. 1991, pp. 10-11.

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⁷Materials Edge (London). *Fothergill Doubles Silica Fabric Capacity*. No. 27, Aug. 1991, p. 14.

⁸———. *Toyota Rolls Out New Materials Concepts*. No. 29, Oct. 1991, p. 4.

⁹———. *MMC Bike Wins Mountain Title*. No. 31, Dec. 1991, p. 12.

¹⁰———. *Kyocera Kick-Starts Ceramic Engines*. No. 22, Mar. 1991.

¹¹Wall Street Journal. *Odds and Ends*. V. 218, No. 44, p. B1.

¹²Engineering News-Record (New York). *Plumbing Code Boosts Use of Glass for Fill*. V. 227, No. 22, Dec. 2, 1991, p. 17.

¹³Industrial Minerals Magazine (London). *3M Dust Respirator*. No. 280, Jan. 1991, p. 64.

¹⁴Cecala, A. B., and A. Covelli. *Automation To Control Silica Dust During the Pallet Loading Process*. *Mining Engineering* (Littleton, CO). V. 43, No. 12, Dec. 1991, pp. 1440-1443.

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Pit & Quarry Magazine.
Rock Products Magazine.

TABLE 1
SALIENT U.S. INDUSTRIAL SAND AND GRAVEL STATISTICS¹

(Thousand short tons and thousand dollars)

	1987	1988	1989	1990	1991
Sold or used:					
Sand:					
Quantity	27,380	27,207	27,819	26,956	24,541
Value	\$357,660	\$376,202	\$395,807	\$420,871	\$377,578
Gravel:					
Quantity	631	1,272	1,385	1,450	1,059
Value	\$6,424	\$11,796	\$14,388	\$15,284	\$12,899
Total industrial:²					
Quantity	28,010	28,480	29,205	28,406	25,600
Value	\$364,100	\$388,000	\$410,200	\$436,200	\$390,477
Exports:					0
Quantity	758	1,060	2,060	1,155	1,637
Value	\$21,253	\$30,843	\$78,308	\$83,826	\$106,606
Imports for consumption:					
Quantity	104	43	35	73	91
Value	\$1,071	\$1,918	\$2,057	\$3,148	\$932

¹Puerto Rico excluded from all industrial sand and gravel statistics.

²Data may not add to totals shown because of independent rounding.

TABLE 2
INDUSTRIAL SAND AND GRAVEL SOLD OR USED IN THE UNITED STATES BY GEOGRAPHIC REGION

Geographic region	1990				1991			
	Quantity (thousand short tons)	Percent of total	Value (thousands)	Percent of total	Quantity (thousand short tons)	Percent of total	Value (thousands)	Percent of total
Northeast:								
New England	154	1	\$3,755	1	148	1	\$4,107	1
Middle Atlantic	2,483	8	37,315	9	2,322	7	34,294	9
Midwest:								
East North Central	9,562	34	124,665	28	8,869	35	120,355	31
West North Central	1,948	7	31,688	7	1,679	7	28,867	7
South:								
South Atlantic	4,098	14	66,430	15	3,986	16	64,837	17
East South Central	1,533	5	17,761	4	1,261	5	15,921	4
West South Central	4,408	16	81,075	19	3,768	15	59,021	15
West:								
Mountain	1,477	5	19,803	5	1,220	5	16,828	4
Pacific	2,745	10	53,663	12	2,348	9	46,247	12
Total¹	28,406	100	436,200	100	25,600	100	390,477	100

¹Data may not add to totals shown because of independent rounding.

TABLE 3
INDUSTRIAL SAND AND GRAVEL SOLD OR USED
IN THE UNITED STATES, BY STATE

(Thousand short tons and thousand dollars)

State	1990		1991	
	Quantity	Value	Quantity	Value
Alabama	878	9,075	531	6,133
Arizona	W	W	W	W
Arkansas	742	7,209	746	7,738
California	2,452	48,055	2,104	41,690
Colorado	W	W	W	W
Connecticut	W	W	W	W
Florida	520	7,024	551	5,989
Georgia	W	W	W	W
Idaho	552	6,234	W	W
Illinois	4,486	62,531	4,146	57,210
Indiana	W	W	W	W
Kansas	W	W	W	W
Kentucky	W	W	W	W
Louisiana	559	10,003	W	W
Maryland	W	W	W	W
Massachusetts	30	401	30	401
Michigan	2,310	19,285	2,093	18,464
Minnesota	W	W	W	W
Mississippi	W	W	W	W
Missouri	W	W	W	W
Montana	W	W	W	W
Nebraska	W	W	W	W
Nevada	607	W	546	W
New Jersey	1,762	26,190	1,634	23,738
New York	W	W	W	W
North Carolina	1,177	15,338	1,174	15,565
Ohio	1,349	24,205	1,294	23,462
Oklahoma	1,258	22,984	1,241	20,918
Pennsylvania	W	W	W	W
Rhode Island	W	W	W	W
South Carolina	844	15,972	822	16,348
Tennessee	W	W	W	W
Texas	1,849	40,880	1,557	27,002
Utah	2	42	—	—
Virginia	W	W	W	W
Washington	W	W	W	W
West Virginia	W	W	W	W
Wisconsin	W	W	W	W
Other	7,027	120,728	7,132	125,820
Total¹	28,406	436,200	25,600	390,477

W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Data may not add to totals shown because of independent rounding.

TABLE 4
INDUSTRIAL SAND AND GRAVEL PRODUCTION IN THE UNITED STATES IN 1991, BY SIZE OF OPERATION

Size range (short tons)	Number of operations	Percent of total	Quantity (thousand short tons)	Percent of total
Less than 25,000	29	19.5	309	1.2
25,000 to 49,999	22	14.9	851	3.3
50,000 to 99,999	26	17.6	1,839	7.2
100,000 to 199,999	27	18.2	3,702	14.5
200,000 to 299,999	14	9.5	3,389	13.2
300,000 to 399,999	12	8.1	4,288	16.8
400,000 to 499,999	7	4.7	3,207	12.5
500,000 to 599,999	2	1.4	1,133	4.4
600,000 to 699,999	3	2.0	1,861	7.3
700,000 and over	6	4.1	5,021	19.6
Total	148	100.0	25,600	100.0

TABLE 5
NUMBER OF INDUSTRIAL SAND AND GRAVEL OPERATIONS AND PROCESSING PLANTS IN THE UNITED STATES IN 1991, BY GEOGRAPHIC REGION

Geographic region	Mining operations on land				Dredging operations	Total active operations
	Stationary	Portable	Stationary and portable	No plants or unspecified		
Northeast:						
New England	4	—	—	—	—	4
Middle Atlantic	8	—	2	1	5	16
Midwest:						
East North Central	31	1	2	—	2	36
West North Central	7	—	—	—	4	11
South:						
South Atlantic	15	—	—	3	7	25
East South Central	11	—	—	—	3	14
West South Central	9	—	—	2	11	22
West:						
Mountain	8	—	—	—	1	9
Pacific	10	—	—	1	—	11
Total	103	1	4	7	33	148

TABLE 6
INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS IN 1991, BY MAJOR END USE

Major use	Northeast			Midwest			South			West			U.S. total ¹		
	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton
Sand:															
Glass-making:															
Containers	1,144	\$16,485	\$14.41	1,817	\$14,849	\$8.17	2,368	\$30,175	\$12.74	1,510	\$26,482	\$17.54	6,839	\$87,992	\$12.87
Flat (plate and window)	W	W	13.24	W	W	9.06	1,569	19,969	12.73	332	5,213	15.70	2,733	32,923	12.05
Specialty	W	W	17.10	411	6,050	14.72	W	W	17.04	23	627	27.26	775	12,497	16.13
Fiberglass (unground)	W	W	4.53	305	3,879	12.72	W	W	7.73	W	W	15.10	490	5,436	11.09
Fiberglass (ground)	—	—	—	W	W	38.20	W	W	35.76	W	W	21.75	314	11,210	35.70
Foundry:															
Molding and core	W	W	14.95	4,107	43,245	10.53	1,047	11,424	10.91	W	W	18.31	5,641	62,289	11.04
Molding and core facing (ground)	—	—	—	W	W	16.35	—	—	—	—	—	—	W	W	16.35
Refractory	W	W	12.83	86	1,113	12.94	W	W	29.09	W	W	24.17	104	1,520	14.62
Metal-lurgical:															
Silicon carbide	—	—	—	W	W	24.11	W	W	9.04	2	45	22.50	246	4,496	18.28
Flux for metal smelting	—	—	—	—	—	—	W	W	6.20	—	—	—	W	W	6.20
Abrasives:															
Blasting	195	4,102	21.04	317	6,869	21.67	1,012	17,841	17.63	182	4,843	26.61	1,706	33,655	19.73
Scouring cleansers (ground)	W	W	62.00	W	W	29.40	W	W	45.29	—	—	—	W	W	29.84
Chemicals (ground and unground)	W	W	23.67	W	W	10.02	W	W	18.66	49	921	18.80	561	9,215	16.43
Fillers (ground):															
Rubber, paints, putty, etc.	15	398	26.53	W	W	81.53	118	8,562	72.56	W	W	18.60	187	13,047	69.77
Silica flour	—	—	—	W	W	38.17	W	W	27.58	W	W	33.00	183	6,679	36.50
Ceramic (ground):															
Pottery, brick, tile, etc.	W	W	18.69	63	2,292	36.38	81	3,237	39.96	W	W	50.00	162	5,878	36.28
Filtration	102	1,754	17.20	63	1,962	31.14	159	2,722	17.12	W	W	30.52	428	9,612	22.46

See footnotes at end of table.

TABLE 6—Continued
INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS IN 1991, BY MAJOR END USE

Major use	Northeast			Midwest			South			West			U.S. total ¹		
	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton
Sand:															
—Continued															
Traction (engine)	W	W	\$2.49	121	\$1,227	\$10.14	55	\$636	\$11.56	W	W	\$14.78	285	\$2,418	\$8.48
Roofing granules and fillers	W	W	13.71	W	W	15.62	274	3,354	12.24	W	W	17.95	647	9,303	14.38
Hydraulic fracturing	—	—	—	1,012	28,962	28.62	W	W	22.55	W	W	25.57	1,355	36,718	27.10
Other uses, specified	934	\$12,939	12.69	1,881	31,312	16.65	1,327	28,647	21.59	774	\$14,660	18.94	XX	XX	XX
Other uses, unspecified ²	69	2,463	35.70	198	4,837	24.43	479	6,533	13.64	234	3,775	16.13	981	17,608	17.95
Total ¹ or average	2,458	38,141	15.52	10,384	146,594	14.12	8,489	133,102	15.68	3,210	59,740	18.61	24,541	377,578	15.39
Gravel:															
Metal-lurgical:															
Silicon, ferro-silicon	—	—	—	W	W	10.00	W	W	12.48	W	W	25.00	582	7,051	12.12
Filtration	12	260	21.67	W	W	50.00	W	W	14.80	—	—	—	63	1,191	18.90
Nonmetal-lurgical flux	—	—	—	—	—	—	—	—	—	W	W	9.22	W	W	9.22
Other uses, specified	—	—	—	164	2,627	16.02	526	6,678	12.70	357	3,334	9.34	415	4,656	11.22
Total ¹ or average	12	260	21.67	164	2,627	16.02	526	6,678	12.70	357	3,334	9.34	1,059	12,899	12.18
Grand total ¹ or average	2,469	38,401	15.55	10,548	149,221	14.15	9,015	139,780	15.51	3,567	63,075	17.68	25,600	390,477	15.25

W Withheld to avoid disclosing company proprietary data; included with "Other uses, specified"; also included in "U.S. total" by use. XX Not applicable.
¹Data may not add to totals shown because of independent rounding.
²Mostly estimated total production plus other uses (small quantities) as reported by producers.

TABLE 7
TRANSPORTATION OF
INDUSTRIAL SAND AND GRAVEL
IN THE UNITED STATES IN 1991
TO SITE OF FIRST SALE OR USE

Method of shipment	Quantity (thousand short tons)	Percent of total
Truck	14,383	56
Rail	10,289	40
Waterway	652	3
Not transported	276	1
Total	25,600	100

TABLE 8
U.S. EXPORTS OF INDUSTRIAL SAND AND GRAVEL, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1990		1991	
	Quantity	F.a.s. value ¹	Quantity	F.a.s. value ¹
North America:				
Canada	806	16,565	1,199	13,515
Mexico	92	1,957	214	4,086
Panama	10	277	11	291
Other	2	305	18	681
Total ²	910	19,105	1,443	18,571
South America:				
Argentina	1	188	4	425
Chile	10	705	4	236
Colombia	1	116	(³)	57
Ecuador	1	176	(³)	52
Peru	1	91	7	278
Venezuela	1	384	2	437
Other	(³)	37	21	419
Total ²	14	1,697	39	1,904
Europe:				
Belgium	24	1,428	9	1,291
Finland	2	67	5	104
France	1	94	1	103
Germany, Federal Republic of	11	2,700	10	3,145
Italy	4	1,055	5	600
Netherlands	15	1,838	10	5,556
United Kingdom	40	872	6	999
Other	5	470	23	1,059
Total ²	99	8,524	72	12,857
Asia:				
Indonesia	32	1,144	2	325
Japan	64	44,867	54	65,114
Korea, Republic of	5	1,872	10	2,520
Singapore	16	4,899	6	2,768
Taiwan	5	849	7	1,179
Other	4	445	1	366
Total ²	125	54,076	80	72,273
Middle East and Africa:				
Ghana	1	31	(³)	12
Israel	2	84	(³)	121
Saudi Arabia	(³)	33	1	275
South Africa, Republic of	(³)	13	(³)	70
Other	(³)	83	(³)	38
Total ²	3	244	1	517
Australia	(³)	165	2	445

See footnotes at end of table.

TABLE 8—Continued
U.S. EXPORTS OF INDUSTRIAL SAND AND GRAVEL, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1990		1991	
	Quantity	F.a.s. value ¹	Quantity	F.a.s. value ¹
Oceania	(°)	10	(°)	39
Grand total²	<u>1,155</u>	<u>83,826</u>	<u>1,637</u>	<u>106,606</u>

¹Value of material at U.S. port of export; based on transaction price, including all charges incurred in placing material alongside ship.

²Data may not add to totals shown because of independent rounding.

³Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF INDUSTRIAL SAND, BY
COUNTRY

(Thousand short tons and thousand dollars)

Country	1990		1991	
	Quantity	C.i.f. value ¹	Quantity	C.i.f. value ¹
Australia	70	2,522	(²)	161
Canada	3	77	1	61
Germany, Federal Republic of	(²)	259	90	629
Japan	(²)	77	(²)	11
United Kingdom	(²)	62	(²)	21
Other	(²)	151	(²)	50
Total³	73	3,148	91	932

¹Value of material at U.S. port of entry; based on purchase price and includes all charges (except U.S. import duties) in bringing material from foreign country to alongside carrier.

²Less than 1/2 unit.

³Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 10
INDUSTRIAL (SILICA) SAND AND GRAVEL: WORLD PRODUCTION,
BY COUNTRY¹

(Thousand short tons)

Country ²	1987	1988	1989	1990	1991 ³
Argentina	9,974	10,645	9,434	9,900	9,920
Australia	2,602	2,170	2,210	2,210	2,205
Austria	754	833	903	902	905
Belgium	2,500	2,698	2,900	2,900	2,315
Brazil	4,020	4,520	4,520	4,100	4,080
Canada	2,934	3,094	2,904	2,094	2,205
Chile ⁴	330	330	330	330	330
Cuba ⁴	571	610	610	550	550
Denmark	2	2	2	3	3
Ecuador	16	55	113	80	77
Egypt ⁴	257	152	597	550	550
Finland	257	300	311	310	300
France ⁴	8,236	8,250	8,250	8,250	3,860
Germany, Federal Republic of:					
Western states	6,755	6,386	6,634	6,756	7,410
Greece ⁴	42	42	67	65	60
Guatemala	34	35	34	33	33
Hungary	696	714	715	599	570
Iceland ⁴	5	5	5	5	5
India	4,173	3,239	2,782	2,860	2,980
Indonesia	967	464	333	182	180
Iran ⁵	667	914	907	761	880
Ireland	6	7	8	8	8
Israel	66	66	72	93	94
Italy ⁴	4,740	4,740	4,960	4,740	4,630
Jamaica	22	14	17	18	18
Japan	4,291	4,630	4,826	4,884	4,775
Kenya	(⁶)	(⁶)	12	12	14
Korea, Republic of	1	2	1	2	2
Malaysia	397	462	498	757	735
Mexico	1,094	1,104	1,341	1,431	1,310
Namibia ⁴	8	7	7	7	7
Netherlands	24,553	28,659	28,271	27,709	27,560
New Zealand	55	61	113	110	45
Norway ⁴	880	880	880	880	880
Pakistan	164	148	200	190	145
Paraguay	2,087	2,123	2,137	2,100	2,200
Peru	84	174	83	110	110
Philippines	185	281	342	322	330
Portugal ⁴	6	6	6	6	6
South Africa, Republic of	2,135	2,216	2,405	2,189	2,280
Spain	1,707	2,668	2,205	2,400	2,205
Sweden ⁴	770	770	770	770	770
Tanzania	7	13	14	7	8
Thailand	169	267	326	465	725
Turkey	438	483	546	600	610

See footnotes at end of table.

TABLE 10—Continued
**INDUSTRIAL (SILICA) SAND AND GRAVEL: WORLD PRODUCTION,
 BY COUNTRY¹**

(Thousand short tons)

Country ²	1987	1988	1989	1990	1991 ³
United Kingdom	⁴ 4,441	4,784	4,828	⁴ 4,555	4,410
United States (sold or used by producers)	28,010	28,480	29,205	28,406	² 25,600
Venezuela	502	502	417	⁴ 488	440
Yugoslavia	2,379	2,231	³ 3,465	² 2,698	2,315
Zimbabwe	45	61	68	⁶ 69	69
Total	¹ 125,034	¹ 131,296	¹ 132,584	¹ 129,468	121,715

⁴Estimated. ²Revised.

¹Table includes data available through June 15, 1992.

²In addition to the countries listed, Angola, Antigua and Barbuda, the Bahamas, China, Israel, New Caledonia, Panama, and the U.S.S.R., among others, produce industrial sand, but current, available information is not adequate to formulate estimates of production levels.

³Reported figure.

⁴Fiscal years beginning July 1 of that stated.

⁵Fiscal years beginning Mar. 21 of that stated.

⁶Less than 1/2 unit.

**TABLE 11
TIME-PRICE RELATIONSHIP FOR
SILICA SAND**

Year	Average annual price, dollars per ton, f.o.b. quarry	
	Actual price	Based on constant 1991 dollars
1971	3.49	11.04
1972	3.81	11.49
1973	3.80	10.77
1974	4.83	12.59
1975	5.50	13.08
1976	5.70	12.75
1977	6.82	14.27
1978	7.65	14.84
1979	8.57	15.31
1980	9.98	16.29
1981	11.15	16.53
1982	12.03	16.80
1983	12.63	16.95
1984	12.92	16.61
1985	12.75	15.80
1986	13.16	15.89
1987	13.06	15.28
1988	13.83	15.57
1989	14.23	15.36
1990	15.61	16.18
1991	15.39	15.39

The implicit price deflators for 1991 are based on "gross domestic product" and not "gross national product," which was used previously. In addition, the base year is 1987, and not 1982, which was used previously.

**TABLE 12
PROJECTIONS AND FORECASTS FOR U.S. INDUSTRIAL SAND, BY END
USE, IN THE YEAR 2000**

(Million short tons)

End use	1991	Year 2000		
		Forecast range		Probable
		Low	High	
Glass sand	11.2	12.0	15.0	13.0
Foundry sand	5.7	7.0	10.0	8.5
Hydraulic fracturing sand	1.4	1.7	2.7	2.3
Other	7.3	8.0	11.0	10.0
Total	25.6	28.7	38.7	33.8

TABLE 13
**TEN-YEAR STATISTICAL DATA FOR INDUSTRIAL SAND SOLD OR USED BY U.S. PRODUCERS, BY
 SELECTED END USES**

(Thousand short tons)

End use	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Glass ¹	12,252	9,436	11,341	10,293	10,993	11,873	12,141	12,293	11,728	11,158
Foundry ²	7,118	6,670	7,239	5,143	5,777	³ 6,932	7,610	³ 7,085	³ 6,333	³ 5,745
Silicon carbide	140	94	135	121	W	130	W	W	191	246
Flux for metal smelting	191	74	97	67	46	114	117	45	23	W
Abrasive ⁴	2,208	1,950	2,030	1,681	1,947	¹ 1,848	2,113	² 2,287	² 2,298	¹ 1,706
Chemicals	335	271	425	378	317	513	655	817	651	561
Fillers	192	141	200	158	267	394	225	227	369	370
Ceramics	226	179	184	150	198	225	280	238	143	162
Filtration	299	102	217	345	494	433	407	310	367	428
Traction (engine)	450	195	246	292	177	465	305	311	314	285
Roofing granules and fillers	517	296	289	403	261	392	575	790	572	647
Hydraulic fracturing	1,481	990	2,057	2,102	1,130	1,396	1,299	1,531	1,839	1,355

W Withheld to avoid disclosing company proprietary data.

¹Includes container, flat, specialty, and fiber (sand and ground sand).

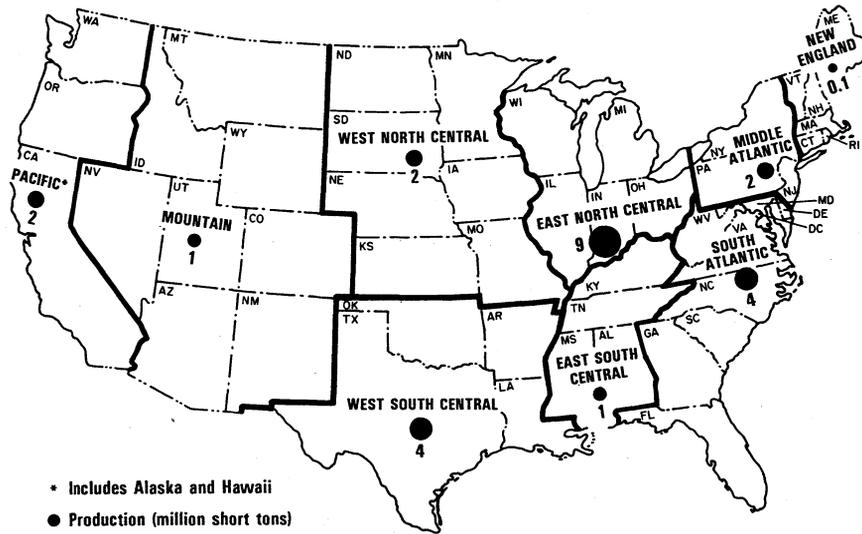
²Includes molding and core, molding and core facings (ground), and refractory uses.

³Excludes molding and core facings (ground).

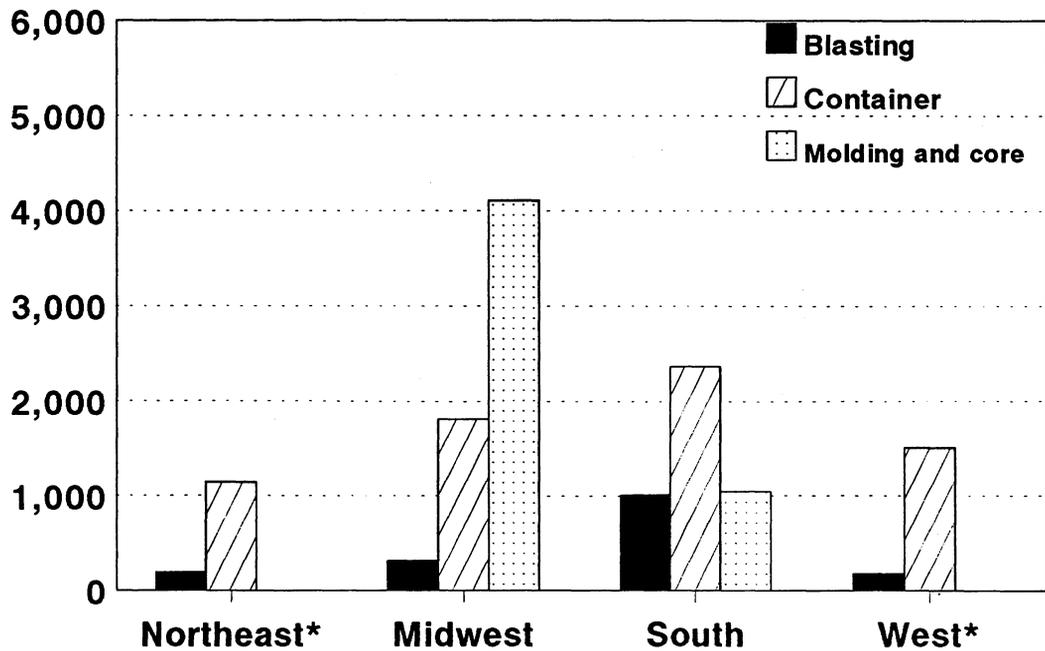
⁴Includes blasting, sawing and sanding (1982, 1984-86), and scouring cleansers (ground).

⁵Excludes scouring cleansers (ground).

**FIGURE 1
PRODUCTION OF INDUSTRIAL SAND AND GRAVEL IN THE UNITED STATES IN 1991,
BY GEOGRAPHIC REGION**



**FIGURE 2
SAND USED IN SELECTED END USES, 1991
(Thousand short tons)**



*Molding and core data withheld to avoid disclosing company proprietary data.

SELENIUM AND TELLURIUM

By Daniel Edelstein

Mr. Edelstein is a physical scientist (geologist) with more than 17 years of combined experience working for the U.S. Bureau of Mines in minerals processing research, process evaluation, and mineral commodities. He has been a commodity specialist for selenium, tellurium, and copper for 9 years.

Domestic demand for selenium declined slightly in 1991. Though domestic production also declined, shipments by domestic producers increased and inventories, which had risen in 1990, declined, resuming the downward trend of the past decade. However, world supply and demand for selenium were nearly in balance, and selenium prices remained remarkably stable throughout the year, with apparently little speculative interest expressed by the market. Environmental concern over high-selenium agricultural drainage water and cadmium sulfoselenide pigments continued.

Following several years of decline, U.S. production, shipments, and consumption of tellurium appeared to stabilize. Imports continued to decline from the high 1988 level.

DOMESTIC DATA COVERAGE

Domestic data for selenium and tellurium are developed from a voluntary survey of the stocks, production, and shipments at the three known domestic producers of selenium and one producer of tellurium. Although all producers responded to the survey, some of the data are withheld to prevent disclosure of company proprietary data.

BACKGROUND

Uses and Products for Trade and Industry

Selenium demand by end use can be divided broadly into four categories: electronic (includes photoconductor uses), glass manufacturing, pigments and chemicals, and other, including

agricultural and metallurgical. In electronics, the largest end-use market, high-purity selenium is used principally as a photoconductor on the drums of plain paper copiers. Other electronics uses include rectifier and photoelectric application. In glass manufacturing, selenium is used principally as a decolorant in container glass and other soda-lime silica glasses. The addition of selenium under weak oxidizing conditions adds a pink color to the glass that combines with the green color imparted by ferrous ions to create a neutral grey color that has low perceptibility to the human eye. Selenium is also used to reduce solar heat transmission in architectural plate glass.

In pigment applications, selenium is used to produce color changes in cadmium sulfide-based pigments. With increasing substitution of selenium for sulfur, the yellow cadmium pigment becomes redder. Sulfoselenide red pigments have good heat stability and are used in ceramics and plastics, as well as paints, inks, and enamels. Because of the relatively high cost and toxicity of cadmium-base pigments, their use is generally restricted to applications requiring long life, brilliance, and high thermal stability and chemical resistance.

Chemical uses of selenium include industrial, pharmaceutical, and biological uses. Small quantities of selenium are used as human food supplements, selenium having been recognized as an essential nutrient for human health. The principal pharmaceutical use of selenium is in antidandruff hair shampoos. Miscellaneous industrial chemical uses include lubricants, rubber compounding, and catalysts.

Dietary supplements for livestock are the largest agricultural usage for selenium. Selenium may also be added directly to fertilizer as a means of increasing selenium content of forage and feed, a practice that is more prevalent outside the United States.

In metallurgical applications, selenium is added to copper, lead, and steel alloys to improve machinability and casting and forming properties. Selenium is added to low-antimony lead alloys used in the support grids of lead-acid storage batteries. The addition of 0.02% selenium by weight as a grain nucleant improves the casting and mechanical properties of the alloy. The quantity of selenium consumed in this application has been greatly affected by technological changes in battery grid manufacture. Development of low-maintenance batteries in the early 1970's encouraged the use of low-antimony grid alloys requiring selenium. Since 1975, lead-calcium maintenance-free automotive batteries have captured a greater share of the automotive battery market. More recently, hybrid batteries, which employ low-antimony lead positive plates and lead-cadmium negative plates, are gaining in usage.

Tellurium is used principally as an alloying element in the production of free-machining low-carbon steels, where additions of up to 0.1% tellurium, usually in conjunction with lead, greatly improve machinability. Similarly, the addition of tellurium to copper and other nonferrous alloys improves their machinability, strength, and corrosion resistance. Tellurium catalysts are used chiefly for oxidation of organic compounds, but are also used in hydrogenation, halogenation, and chlorination reactions. Tellurium

chemicals are used as curing and accelerating agents in rubber compounding. Electronic semiconductor applications for high-purity tellurium include its use with selenium as a photoconductor in plain paper copiers, in thermoelectric and photoelectric devices, and in optical disk storage systems. Mercury-cadmium-telluride (MCT) is used as a sensing material for thermal imaging devices.

Geology-Resources

Selenium and tellurium are relatively rare elements, having estimated crystal abundances of 0.05 part per million and 0.5 to 10 parts per billion, respectively.¹ Selenium and tellurium are frequently found in base metal sulfide minerals. Selenium can isomorphously replace sulfur in the crystal lattice while tellurium is usually found in discrete minerals or microsegregations in the host sulfide mineral.² The most common occurrence of tellurium is as a gold and/or silver telluride.

The concentrations of selenium and tellurium in nature are insufficient to allow for their economic recovery as principal products. Recovery of these elements is therefore dependent on their concentration during the processing of nonferrous ores, principally copper-bearing ores. World reserves of selenium and tellurium are difficult to assess on a deposit by deposit basis. A simplified estimate may be obtained by applying assumed recovery factors to world copper reserves. Total reserves of selenium and tellurium thus estimated were 80,000 metric tons and 22,000 metric tons, respectively. A higher recovery factor was applied to Canada owing to the unusually high selenium content of eastern Canada copper reserves. The aforementioned estimates exclude resources of selenium and tellurium contained in lead, zinc, and gold reserves, which at times have served as sources of these materials, and in coal reserves.

The selenium content of coal averages about 1.5 parts per million. Various studies have indicated that between 5%

and 90% of the selenium contained in coal is released to the atmosphere in either vapor form or as fine particles that escape pollution control devices. Coal combustion is the major anthropogenic source of atmospheric selenium. It has been estimated that combustion of fossil fuels, especially hard coal, accounts for about 35% of total anthropogenic atmospheric selenium emissions of 6,300 tons per year. However, anthropogenic sources account for only 40% of estimated annual global emissions, the balance coming from natural sources such as dust, volcanos and hot springs, sea salt spray, and vegetative emissions.³

Technology

In processing copper ores, selenium and tellurium accumulate along with the precious-metals values in the anode slimes generated during electrolytic refining. Anode slimes typically contain only 10% selenium and 2% tellurium, but may contain up to 30% and 8%, respectively. Decopperized anode slimes are treated by one of several chemical and pyrometallurgical process schemes, first to segregate the selenium and tellurium from the precious-metal residues and secondly to refine the crude selenium and tellurium intermediates. In one process, decopperized slimes are roasted with soda ash to produce water-soluble selenates and selenides. If present, insoluble tellurium may be acid leached from the residue. A second method involves sulfatization, where slimes are digested in sulfuric acid at elevated temperature to sulfatize the base metals and oxidize the selenium. Thin layer roasting of the sulfatized slimes volatilizes the selenium dioxide, which is then precipitated upon cooling.

Most of the selenium and tellurium initially present in the sulfide ores is never recovered, because process circuits are optimized for recovery of copper in the concentration, smelting, and refining stages and precious metals in the slimes processing circuits. In the case of selenium, only 25% to 60% of the selenium in the smelter feed is recovered in the blister, and only 30% to 80% of

the selenium concentrated in the anode slimes is recovered, compounding losses as the processing progresses. Assuming an emissions factor of 120 grams per ton of primary smelter production, copper smelters emit about 1,000 tons per year of selenium to the atmosphere.⁴

ANNUAL REVIEW

Legislation and Government Programs

Since the early 1970's, the Food and Drug Administration (FDA) has been dealing with the issue of selenium addition to animal feeds. Selenium is an essential dietary micronutrient, and much of the forage and grain grown in the United States contains insufficient selenium to meet dietary needs. Since 1974, when the original food additive regulation for selenium was approved, regulations concerning selenium animal feed supplementation have been amended eight times. In April 1987, the permitted supplementation levels were increased from 0.1 or 0.2 part per million, depending on the animal, to 0.3 part per million in complete animal feed. In issuing that amendment, the FDA found that the increased supplementation level would have no significant environmental impact. However, several organizations filed objections to that "finding of no significant impact" (FONSI), and requested a hearing and/or stay of the 1987 amendments. At issue was whether or not increased excretion of selenium by animals ingesting the higher levels of selenium would be of sufficient quantity and bioavailability to cause significant adverse environmental impacts, particularly in aquatic systems. This was of particular concern given that animal feces are used for soil supplementation; some areas where supplementation might occur are contaminated with selenium from existing water-management practices, and wildlife from those areas have already been adversely affected.

In July 1989, the Center for Veterinary Medicine (CVM) of FDA published its preliminary analysis of objections to the 1987 amendments and invited further comments before issuing a final

conclusion. In its issue analysis, CVM affirmed the nutritional justification for selenium supplementation and concluded that its initial FONSI grossly overestimated the potential mobility and bioavailability, and therefore, the potential negative impact of selenium entering the environment as a consequence of the 1987 amendment. At yearend 1991, CVM had yet to finalize its analysis and continued to operate under the guidelines of the 1987 amendment.

Issues

The impact on selenium consumption that limitations on cadmium use could have was a major issue of concern to selenium producers. The principal use of selenium in pigments is to modify the color of yellow cadmium pigments. Cadmium sulfoselenide pigments (CSP's) are widely used in plastics because of their high thermal, chemical, and ultraviolet stability. Worldwide, about 10% of selenium demand was for pigments and about 80% of CSP's was used in plastics. The toxicity of cadmium and concerns over leachability of CSP's has already led to restriction of usage in some applications, particularly those associated with foodstuffs and toys. A European Community directive intended to harmonize CSP restrictions within member countries, which was scheduled to take effect on January 1, 1993, but which was believed to be impacting CSP usage already, restricts CSP use in those resins and polymers where their use is not seen to be essential. The 1993 restriction was limited to polymers for which pigment substitutes were already available. The directive also proposed a future ban, beginning in 1996, for a list of polymers for which it anticipated that it might be possible to demonstrate satisfactory substitutes. Though tests have shown cadmium leaching from plastics to be low, further restrictions, such as banning landfill disposal of CSP-containing plastics, could further impact this segment of the selenium market.

Production

Primary selenium was recovered in the United States at three electrolytic copper refineries: ASARCO Incorporated at Amarillo, TX; Phelps Dodge Refining Corp. at El Paso, TX; and Rio Tinto Zinc Corp. Ltd. at its Kennecott refinery at Magna, UT. Commercial-grade tellurium metal and tellurium dioxide were produced only by Asarco. Selenium- and tellurium-containing anode slimes or residues generated at other domestic primary copper refineries were exported for processing. In addition to commercial-grade tellurium, Asarco produced some high-purity electronics-grade material (99.999% tellurium) at its refinery in Globe, CO. Detector-grade tellurium (99.99999% tellurium), suitable for use in infrared imaging devices, was produced by Cabot Corp., Boyerstown, PA.

Most domestic selenium was produced as commercial-grade material, averaging a minimum of 99.5% selenium and available in various forms, including shot, powder, and lumps, or as pigment-grade powder having a minimum 99.8% selenium content. The largest end use for domestic selenium was in glass manufacturing. There was no domestic production of high-purity selenium suitable for electronic applications. Selenium contained in scrap derived from the manufacture of photoconductor drums and from used photoreceptor drums was exported for processing. There was no domestic production of secondary selenium.

Domestic production of refined selenium declined in 1991 despite record mine production of copper. The discrepancy resulted from a decline in primary smelter and electrolytic refined copper production, the increase in mine production coming from leaching/solvent extraction-electrowinning. The decline is also a reflection of the "bottleneck" in global and domestic copper smelting capacity. U.S. net exports of copper concentrates increased by about 25,000 tons from the already high level of 1990. Production by Kennecott was negatively

impacted by smelter curtailments imposed by State environmental regulations.

Consumption and Uses

Domestic demand for selenium fell slightly, continuing a 3-year decline, owing to poor photoreceptor demand, weakness in the automotive industry, and environmental pressure to reduce the use of cadmium-containing materials. Demand for selenium in glass manufacturing was reported to be strong. Demand for selenium by end use was estimated as follows: electronics, 35%; pigments and chemicals, 20%; glass manufacturing, 30%; and other, including agriculture and metallurgy, 15%.

Excluded from the 1991 apparent consumption estimate of 520 tons were about 14 tons of selenium contained in imported selenium dioxide and an undifferentiated quantity of imported sodium selenite and miscellaneous compounds. In 1988, the last year for which trade data on sodium selenite were available, 41 tons of selenium contained in selenite was imported, principally for use as an animal feed additive. Apparent domestic demand for tellurium in 1991, as calculated from production, stock, and trade data, increased slightly, reversing a downward trend and was increasingly met by domestic production. The war in the Persian Gulf may have served to boost demand for high-purity tellurium used in MCT thermal imaging devices for night vision. High-purity tellurium, however, accounted for only a small part of the tellurium market.

Markets and Prices

The merchant price for commercial-grade, 99.5% selenium metal, quoted by Metals Week on a weekly basis, remained remarkably stable throughout the year, with only a slight decline at midyear when the quoted price fell from the yearend 1990 quoted range of \$5.40 to \$5.70 per pound to \$5.10 to \$5.35 per pound. Intermerchant prices in Rotterdam warehouses, as reported by Metals Bulletin, were also stable. Quotations fell within the \$4.80 and

\$5.40 range throughout the year. The upper limit came down slightly to \$5.30 at midyear. Pigment-grade material, minimum 99.8% selenium, traded at about a \$0.50 per pound premium to commercial-grade material. Significant premiums, \$10.00 to \$20.00 per pound, were charged for higher purity forms of selenium.

The price for commercial-grade tellurium metal remained essentially unchanged during the year despite overall easing in the availability tightness that had caused a near tripling of prices between 1986 and 1988. The yearend price quote for tellurium by the only domestic producer was \$32 per pound.

World Review

World production of refined selenium remained at about the same high level as in 1990. According to data compiled by the Selenium Tellurium Development Association, Inc. (STDA), Western World supply and demand for refined selenium were nearly balanced during 1991, though inventories rose slightly at reporting companies owing to outside purchases. STDA data reflect shipments and inventories from companies that accounted for between 70% and 80% of Western World supply. While apparent demand declined in the United States and Europe, apparent demand in Japan, as calculated from production and trade, increased, and exports to China rose to more than 150 metric tons. Exports to China during the previous 3 years averaged only 85 tons per year.

World production and consumption data for refined tellurium were limited. According to STDA data, shipments of refined tellurium by producers outstripped production, and stocks fell slightly during the year. STDA data reflect shipments and inventories from companies that accounted for between 60% and 70% of Western World supply. Ferrous and nonferrous alloys accounted for most of the identifiable market.

Capacity.—While many market economy countries mine copper, only about 15 countries and 20 refineries

reported recovery of primary selenium, and about one-half the latter reported tellurium production. Several primary refiners of selenium also recovered selenium from scrap, though breakout of their primary and secondary production is not well documented. Several companies, including Pacific Rare Metal Industries Inc. (formerly International Recoveries Inc.) in the Philippines, Shinko Chemicals Co. Ltd. and Asia Bussei Zairyo in Japan, and Mineral and Chemical Products Ltd. in the United Kingdom, were believed to produce selenium exclusively from secondary materials. Capacity estimates for principal primary producers are shown in table 8.

Canada.—One company, Noranda Inc., accounted for all of Canada's refined selenium production. Inco Ltd. discontinued production of refined selenium in 1988 and began exporting crude selenium and tellurium. According to Energy Mines and Resource Canada, Inco can produce 45 tons and 4.5 tons per year of selenium cake and tellurium dioxide cake, respectively. In addition to its own material, Noranda processes anode slimes at its Canadian Copper Refiners (CCR) Div. from Hudson Bay Mining and Smelting Co. Ltd. and Kidd Creek Mines Ltd. The Kidd Creek ore body is reported to be the world's largest single source of selenium. While anode slimes from electrolytic refining of copper typically contain between 2% and 10% selenium, Kidd Creek slimes contain about 20% selenium. CCR is the world's largest producer of selenium and has an estimated capacity of about 400 tons per year. CCR commissioned a new slimes treatment plant in 1988.

Japan.—Primary selenium and tellurium are produced by four companies in Japan having a combined estimated capacity of about 500 and 100 tons per year, respectively. At yearend 1989, Mitsubishi Metal Corp., Japan's largest producer, commissioned a new precious-metals refinery at Naoshima, reportedly closing its Osaka slimes recovery unit. Annual capacities for selenium and

tellurium at the new facility were reported to be 200 tons and 18 tons, respectively. Capacities at the Osaka plant had been reported to be 250 tons and 60 tons, respectively. Nippon Mining Co. Ltd. was Japan's second largest producer, followed by Sumitomo Metal Mining Ltd. and Mitsui Mining and Smelting Co. Ltd.⁵

OUTLOOK

Production and consumption of selenium have fluctuated over time. Because primary selenium is recovered as a byproduct of other nonferrous metals, its availability is influenced by the supply-demand cycles of the principal metals. High demand-production for the principal material has led to excess production of selenium. Similarly, owing to its limited application in specialized areas, technological changes or government regulation have caused rapid shifts in demand. For example, apparent domestic demand for selenium in 1970 and 1991 were both about 500 tons. However, demand slipped during the 1970's to below 400 tons owing to replacement of selenium by silicon in most rectifier applications. The development and growth in the photocopier market led to a resurgence in electronics demand for selenium. The domestic copper production cycle, however, was out of phase with selenium demand. High copper production of the late 1970's corresponded to weak selenium demand, and depressed copper production in the early 1980's corresponded to a growth period in selenium demand. Consequently, stocks of selenium rose to a peak level in 1981, before beginning a 10-year slide. The selenium supply-demand balance entered a transition period in 1990, when demand fell, production increased, and the slide in inventories was halted. World production and consumption were balanced in 1991.

The outlook for selenium demand, based on existing application, is not encouraging. As noted before, demand for selenium in pigment applications has already begun to show the impact of

increased environmental concern over the use of cadmium-base pigments. Similarly, photocopier markets for selenium are expected to decline or remain stable owing to competition from other technologies, including organic photoreceptors and laser printing. On the positive side, demand for selenium compounds in agricultural uses is expected to remain stable or even increase, though environmental concerns could limit its increase. Demand in this application increased significantly, along with imports of sodium selenite, in 1987, following the new FDA regulations. The market for selenium in glass is expected to remain strong.

The U.S. Bureau of Mines forecasts a significant increase in world copper mine capacity for the next 5 years. Several major refiners of selenium have modernized their facilities over the past few years, and several new selenium refineries have opened. Since 1985, world capacity has increased by about 200 tons. Thus, production of refined selenium is expected to meet or exceed world demand. New technologies, such as photovoltaic solar cells and free-machining brass alloys as a replacement for leaded brass in plumbing systems, could create new markets and alter the supply-demand balance. Increased exports to China could further boost demand.

Though tellurium, like selenium, is recovered strictly as a byproduct of other nonferrous metals, principally copper, its production cycle has shown significant independence relative to copper production. World production of tellurium has trended downward since 1979, following the downward trend in world demand. Excess supply, an extended period of weak prices, and reduced tellurium content of ores processed have contributed to lost production. By the end of 1987, available supplies fell short of even the reduced world demand, and prices climbed to their current levels. Since that time, the supply and demand for refined tellurium has maintained a tight balance.

The near-term outlook is for a continuation of the tight balance between

tellurium supply and demand. Tellurium's high price is expected to moderate future demand for it in traditional metallurgical applications and stimulate the substitution of alternative materials. Demand for high-purity tellurium for use in thermal imaging and optical storage devices is expected to grow but not have significant impact on overall demand. If new thin-film technologies stimulate the demand for tellurium in electronic applications, such as solar energy conversion or thermoelectric power generation, supply pressures could increase. Though no significant new tellurium capacity is expected, low-grade tellurium residues from anode slimes that are not currently processed could become economic to treat. Also, anticipated growth in copper mine and electrolytic refinery production will increase slimes generation and could result in increased tellurium production. Little public information is available on the selenium and tellurium content of new ore bodies scheduled for development.

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TABLE 1
SALIENT SELENIUM AND TELLURIUM STATISTICS

(Kilograms of contained metal unless otherwise specified)

	1987	1988	1989	1990	1991
SELENIUM					
United States:					
Production, primary refined	W	285,633	253,427	286,755	259,522
Shipments to consumers	W	260,838	294,672	250,450	283,656
Exports, metal, waste and scrap	162,217	243,096	372,126	¹ 194,608	210,495
Imports for consumption	495,862	474,234	¹ 417,095	¹ 382,860	¹ 347,728
Apparent consumption, metal ²	W	590,000	560,000	530,000	520,000
Stocks, yearend, producer	W	W	W	W	W
Dealers' price, average per pound, commercial-grade ³	\$6.51	\$9.84	\$7.61	\$5.82	\$5.41
World: Refinery production	⁴ 1,421,293	¹ 1,684,712	¹ 1,603,987	¹ 1,793,633	¹ 1,808,551
TELLURIUM					
United States:					
Imports for consumption	26,700	76,890	⁵ 42,87	⁵ 34,012	⁵ 29,255
Producer price quote, yearend, commercial-grade, per pound	\$20.00	\$35.00	\$34.00	\$31.00	\$32.00

¹Estimated. ²Revised. W Withheld to avoid disclosing company proprietary data.

³Includes unwrought and waste and scrap and selenium dioxide.

⁴Calculated using reported shipments, imports of selenium metal, and estimated exports of selenium metal, excluding scrap.

⁵Source: Metals Week. Calculated from published price ranges.

⁶Excludes the United States.

⁷Includes only unwrought and waste and scrap.

TABLE 2
U.S. EXPORTS OF SELENIUM METAL, WASTE AND SCRAP, BY COUNTRY

Country	1989		1990		1991	
	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value
Belgium	40,650	\$658,524	11,794	\$71,454	2,670	\$26,200
Benin	3,614	57,760	—	—	—	—
Brazil	362	22,640	2,396	88,633	—	—
Canada	9,766	161,518	44	1,195	3,003	89,079
Chile	2,040	29,908	1,590	18,143	—	—
China	—	—	—	—	17,163	206,950
Colombia	4,000	52,720	—	—	8,637	96,628
Djibouti	—	—	707	11,300	—	—
France	—	—	240	2,637	—	—
Germany, Federal Republic of	7,570	81,589	14,717	165,576	13,447	150,706
India	4,186	66,910	—	—	3,166	71,095
Indonesia	—	—	(¹)	(¹)	—	—
Italy	507	5,282	—	—	—	—
Japan	86,839	322,632	44,283	226,017	65,771	425,014
Korea, Republic of	998	29,887	450	10,000	1,895	46,090
Mexico	35,921	304,199	24,466	355,142	18,312	262,939
Netherlands	57,308	730,817	3,500	31,000	6,670	72,687
Norway	—	—	—	—	17,590	266,108
Philippines	—	—	—	—	26,677	39,363
Senegal	1,664	22,130	—	—	—	—
Sierra Leone	11,035	21,749	—	—	—	—
Singapore	30,623	417,150	513	8,200	—	—
Spain	1,044	12,461	—	—	—	—
Tanzania	4,097	65,480	—	—	—	—
Uganda	2,891	46,200	—	—	—	—
United Kingdom	47,610	235,759	89,682	288,855	20,978	115,768
Venezuela	—	—	226	5,000	—	—
Zaire	16,808	44,973	—	—	—	—
Other	2,593	39,136	—	—	4,516	70,615
Total	372,126	3,429,424	194,608	\$1,283,152	210,495	1,939,242

¹Revised.

¹Revised to zero.

Source: Bureau of the Census.

TABLE 3
U.S. IMPORTS FOR CONSUMPTION OF SELENIUM, BY CLASS AND COUNTRY

Class and country	1989		1990		1991	
	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value
Unwrought and waste and scrap:						
Belgium	73,654	\$2,234,265	52,063	\$1,962,260	43,947	\$1,759,005
Brazil	—	—	100	5,044	—	—
Canada	102,507	2,368,336	112,857	2,553,992	156,303	3,746,619
China	2,000	4,761	—	—	—	—
Finland	—	—	2,200	24,188	11,200	119,984
Germany, Federal Republic of	10,566	274,700	17,088	365,861	5,670	102,028
Hong Kong	2,268	78,600	—	—	—	—
Japan	65,266	1,517,688	51,307	1,102,083	56,709	1,259,330
Kenya	—	—	—	—	8,217	10,740
Korea, Republic of	12,514	188,780	7,999	91,311	401	47,075
Netherlands	6,940	106,960	2,986	72,532	—	—
Peru	—	—	—	—	1,800	18,651
Philippines	12,910	143,243	30,153	321,908	7,492	77,300
Spain	10	1,070	—	—	—	—
Sweden	—	—	—	—	3,000	36,610
United Kingdom	69,631	1,173,918	82,684	1,619,921	38,550	637,182
Venezuela	920	10,103	—	—	—	—
Yugoslavia	40,320	491,760	18,315	166,948	—	—
Total	399,506	8,594,184	377,752	8,286,048	333,289	7,814,54
Selenium dioxide:						
Belgium	1,241	40,730	—	—	—	—
Germany, Federal Republic of	6,296	109,263	157	4,603	13,839	196,903
India	229	3,650	—	—	—	—
United Kingdom	9,823	186,431	4,951	62,713	600	10,710
Total¹	17,589	340,074	5,108	67,316	14,439	207,613
Grand total	417,095	8,934,258	382,860	8,353,364	347,728	8,022,173

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census, figures adjusted by the U.S. Bureau of Mines.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF TELLURIUM, BY CLASS AND COUNTRY

Class and country	1989		1990		1991	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Unwrought and waste and scrap: ¹						
Australia	8,030	\$256,379	—	—	—	—
Belgium	5,485	463,840	4,638	\$379,566	4,858	\$509,909
Canada	10,637	1,117,746	11,191	2,039,593	5,528	960,723
China	—	—	1,230	89,972	—	—
France	—	—	310	14,601	447	6,354
Germany, Federal Republic of	3,904	442,614	4,415	507,349	2,164	362,409
Japan	1,802	209,261	1,110	162,572	1,739	208,961
Mexico	699	40,874	70	3,704	1,177	41,226
Netherlands	3,604	241,229	—	—	—	—
Philippines	240	15,121	—	—	—	—
Switzerland	—	—	—	—	3	1,377
Peru	—	—	1,072	70,452	—	—
United Kingdom	8,470	462,036	9,976	660,587	13,339	981,820
Total	42,871	3,249,100	34,012	3,928,396	29,255	3,072,779

¹Listed as "tellurium" under the Harmonized Tariff System and grouped together with boron. However, imports of boron are thought to be very small relative to tellurium.

Source: Bureau of the Census.

TABLE 5
U.S. SELENIUM AND TELLURIUM IMPORT DUTIES

Tariff item	HTS No.	Most favored nation (MFN) Jan. 1, 1992	Non-MFN Jan. 1, 1991
Selenium	2804.90.0000	Free	Free.
Selenium dioxide	2811.29.2000	Free	Free.
Tellurium	2804.50.0000	Free	25.0% ad valorem.

TABLE 6
SELENIUM: WORLD REFINERY PRODUCTION, BY COUNTRY¹

(Kilograms, contained selenium)

Country ²	1987	1988	1989	1990	1991 [*]
Belgium [*]	230,000	250,000	250,000	250,000	250,000
Canada ³	300,000	321,000	270,000	³ 369,000	395,000
Chile	45,909	47,051	⁴ 48,200	⁴ 49,400	50,600
Finland	² 23,638	² 25,073	² 27,969	³ 31,160	30,000
Germany, Federal Republic of: Western states [*]	100,000	100,000	100,000	110,000	110,000
India	4,026	5,103	4,261	³ 3,840	4,000
Japan	481,109	471,020	470,028	494,692	⁴ 537,429
Mexico	29,000	13,000	20,000	¹ 12,000	² 2,000
Peru	11,430	4,937	¹ 9,000	⁸ 8,913	9,000
Philippines ⁵	72,000	58,000	55,000	⁷ 70,000	60,000
Sweden	31,000	¹ 19,000	² 20,000	² 27,000	25,000
United States	W	285,633	253,427	286,755	⁴ 259,522
Yugoslavia	66,362	60,812	⁵ 55,241	⁵ 59,181	55,000
Zambia ⁶	26,819	24,083	² 20,861	² 21,692	21,000
Total	¹1,421,293	¹1,684,712	¹1,603,987	¹1,793,633	1,808,551

^{*}Estimated. ²Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

¹Insofar as possible, data relate to refinery output only; thus, countries that produced selenium contained in copper ores, copper concentrates, blister copper and/or refinery residues, but did not recover refined selenium from these materials indigenously, were excluded to avoid double counting. Table includes data available through June 24, 1992.

²In addition to the countries listed, Australia and the U.S.S.R. produced refined selenium, but output is not reported, and available information is inadequate for formulation of reliable estimates of output levels. Australia is known to produce selenium in intermediate metallurgical products and has facilities to produce elemental selenium. In addition to having facilities for processing imported anode slimes for the recovery of selenium and precious metals, the United Kingdom has facilities for processing selenium scrap.

³Excludes secondary production.

⁴Reported figure.

⁵Incomplete; data shown are for primary production at Philippine Associated Smelting and Refining Corp.

⁶Data for fiscal year beginning Apr. 1 of year stated.

TABLE 7
TELLURIUM: WORLD REFINERY PRODUCTION, BY COUNTRY¹

(Kilograms, contained tellurium)

Country ²	1987	1988	1989	1990	1991 [*]
Canada ³	13,000	¹ 10,000	8,000	13,000	12,000
Japan	53,305	55,181	51,031	49,701	⁴ 57,497
Peru	7,457	4,078	⁸ 3,337	⁷ 8,842	9,300
United States	W	W	W	W	W

^{*}Estimated. ²Revised. W Withheld to avoid disclosing company proprietary data.

¹Insofar as possible, data relate to refinery output only; thus, countries that produced tellurium contained in copper ores, copper concentrates, blister copper, and/or refinery residues, are excluded to avoid double counting. Table is not totaled because of the exclusion of data from major world producers, notably the U.S.S.R. and the United States. Table includes data available through June 5, 1992.

²In addition to the countries listed, Australia, Belgium, the Federal Republic of Germany, and the U.S.S.R. are known to produce refined tellurium, but output is not reported, and available information is inadequate for formulation of reliable estimates of output levels. Moreover, the other major copper-refining nations such as Chile and Zambia may produce refined tellurium, but output in these nations is conjectural.

³Primary recoverable output.

⁴Reported figure.

TABLE 8
PRINCIPAL MARKET ECONOMY COUNTRY PRODUCERS OF
SELENIUM AND TELLURIUM AND ANNUAL CAPACITY, 1991

(Metric tons)

Continent and country	Company	Primary capacity	
		Selenium	Tellurium
North America:			
Canada	Noranda Mines Ltd.	¹ 400	40
Mexico	Cobre de Mexico S.A.	45	—
United States	ASARCO Incorporated	W	W
	Kennecott, Utah Copper Corp.	W	—
	Phelps Dodge Corp.	W	—
Total United States		400	W
South America:			
Brazil	Cariaba Metais S.A. Industria e Comercio	20	—
Chile	Empresa Nacional de Minería	40	—
Peru	Empresa Minera del Centro del Peru	20	20
Europe:			
Belgium	Metallurgie Hoboken-Overpelt S.A.	¹ 360	100
Finland	Outokumpu Oy	90	—
Germany, Federal Republic of	Norddeutsche Affinerie AG	120	50
Sweden	Boliden Metall AB.	70	—
Yugoslavia	Rudarsko Topionicarski Bazen Bor	70	—
Africa: Zambia	Zambia Consolidated Copper Mines Ltd.	25	—
Asia:			
Japan	Mitsubishi Metal Corp.	200	60
	Mitsui Mining and Smelting Co. Ltd.	60	15
	Nippon Mining Co. Ltd.	120	15
	Sumitomo Metal Mining Co. Ltd.	70	10
Philippines	Pacific Rare Metals Industries Inc.		
	Philippine Associated Smelting and Refining Corp.	(²)	³ 100
Grand total		2,120	W

W Withheld to avoid disclosing company proprietary data.

¹Includes secondary capacity.

²Secondary selenium capacity is about 100 tons per year.

³Tellurium dioxide and tellurium metal; tellurium content.

SILICON

By Larry D. Cunningham

Mr. Cunningham, a physical scientist with 12 years U.S. Bureau of Mines experience, has served as the commodity specialist for silicon since February 1992. Domestic survey data and trade data were prepared by Ms. Robin Johnson, statistical assistant.

Silicon (Si) is a light chemical element with both metallic and nonmetallic characteristics. In nature, silicon combines with oxygen and other elements to form silicates. Silicon in the form of silicates constitutes more than 25% of the Earth's crust. Silica is a silicate consisting entirely of silicon and oxygen. Silica (SiO₂) as quartz or quartzite is used to produce silicon-base products for the iron, steel, aluminum, and chemical industries.

Silicon metal prices improved from those of the previous year, but the price for ferrosilicon continued its decline as supply continued to exceed demand. Based on contained silicon, overall domestic production fell to about 365,000 metric tons, and consumption of silicon decreased to 500,000 metric tons.

Overall U.S. trade volume of silicon exports was down by 8%, while overall trade volume of silicon imports decreased by more than 30%. Dumping tariffs were levied against U.S. imports of silicon metal from Argentina, Brazil, and China. U.S. net import reliance for silicon products was estimated to be 27%.

The metric system is the official system of measurement of most countries. The U.S. Bureau of Mines, in an effort to provide statistical data on silicon that are consistent with international usage, reports data in kilograms and metric tons unless otherwise noted. For comparison to data published in short tons prior to 1990, metric tons can be converted into short tons by multiplying the published number by 1.10231.

DOMESTIC DATA COVERAGE

Domestic production data for the silicon commodity are developed by the U.S. Bureau of Mines by means of monthly and annual voluntary surveys. The "Silicon Alloys" survey canvasses the operations listed in table 2. The figures in table 1 represent 100% of the production and shipments from these operations.

BACKGROUND

Definitions, Grades, and Specifications

Silicon metal and ferrosilicon are referred to by the approximate percentage of silicon contained in the material and by the maximum amount of trace impurities present. There are two standard grades of ferrosilicon, with one grade approximately 50% silicon and the other 75% silicon by weight. In addition to the standard grades of ferrosilicon, there are miscellaneous silicon alloys that contain silicon and other elements. The most common of these alloys are magnesium ferrosilicon and calcium silicon. However, other elemental additions include barium, boron, manganese, strontium, and titanium.

Metallurgical-grade and polycrystalline silicon metal are referred to by their minimum silicon content and maximum impurity level. Typical impurities cited for metallurgical silicon metal are aluminum, calcium, and iron. Typical polysilicon impurities include carbon, boron, and phosphorus and are commonly

measured at the parts per million and parts per billion levels.

The American Society for Testing and Materials (ASTM) publishes standards for ferrosilicon and silicon metal. ASTM Specification A100 covers seven regular grades of ferrosilicon for steelmaking and foundry uses designated A, B, C, D, E, F, and G, and subgrades designated as low-aluminum, boron-bearing, and calcium-bearing. ASTM Specifications A518 and A861 covers high-silicon cast iron castings and high-silicon iron pipe and pipe fittings for corrosion-resistant uses. ASTM recommends that the producer furnish with each shipment an analysis showing the silicon content and, on request, also include aluminum, carbon, manganese, phosphorus, and sulfur contents. Semiconductor Equipment and Materials International (SEMI) has published standards for both polycrystalline and single crystal grades of silicon.

Products for Trade and Industry

Several grades of ferrosilicon are produced and sold in the United States. However, most of the ferrosilicon consumed domestically in 1991 was either 50%- or 75%-grade material, the majority being 50%-grade. The domestic silicon industry supplies nearly all of the 50%-grade material and about 70% of all ferrosilicon products. Miscellaneous silicon alloys consumed in the United States consist primarily of magnesium ferrosilicon. Almost all ferrosilicon products are consumed by the iron and steel industries.

Metallurgical-grade silicon metal is used by the primary aluminum, secondary aluminum, and chemical industries. The products sold to these industries vary considerably in their specifications. The chemical and primary aluminum industries generally require more stringent specifications than those of the secondary aluminum industry. In addition, the chemical industry requires that the metal be ground into a fine powder rather than the lump form used by the aluminum industries.

Geology-Resources

The United States has an abundance of silica deposits for the production of ferrosilicon and silicon metal. For the production of these materials, 98% to 99% purity is preferred. However, trace amounts of aluminum and iron are also acceptable. Physically, the material should not contain fines and should not crumble easily.

Technology

Silicon metal and ferrosilicon are produced by the reduction of silica (SiO_2) to silicon (Si) in a submerged arc electric furnace. A typical charge consists of silica as beneficiated quartz or quartzite; coal, coke, or charcoal as a reductant; wood chips for porosity; and, when producing ferrosilicon, iron in the form of steel scrap or iron ore. During the furnace operation, raw materials are periodically charged into the top of the furnace, and the molten metal or alloy is periodically tapped at the bottom of the furnace and cast into chills or ingots. The material is then crushed to specific size requirements starting at about 20 centimeters down to 200 mesh.

Metallurgical-grade silicon metal is the starting material for high-purity silicon consumed by the electronics industry. First, silicon metal is used to produce an intermediate product such as silicon trichlorosilane (TCS). A vapor deposition process is then used to form a rod or boule of high-purity polycrystalline silicon (polysilicon) from the TCS. A single crystal boule is made from

polysilicon by two methods. The Czochralski (CZ) method uses a seed crystal to grow a rod of single crystal silicon from a molten crucible of polysilicon. The Float Zone (FZ) method uses an induction coil to produce a molten zone within a rod of polysilicon. The coil starts at one end of the boule where a seed crystal starts the crystal growth. The coil moves slowly down the boule, allowing a single crystal to be formed. After being sliced into wafers, the silicon is used by the electronics industry to produce integrated circuits.

Byproducts and Coproducts

Silicon metal and ferrosilicon furnaces produce a material that is referred to as silica fume, silica dust, or microsilica. Originally, this material was considered of little or no value. However, microsilica is now used as an additive in a number of different products, including high-strength concrete. Research is ongoing to find additional uses for this material.

Economic Factors

Production of silicon metal or ferrosilicon is extremely power intensive, requiring a power input of about 8,000 kilowatt-hours per ton of 75%-grade and 12,000 kilowatt-hours per ton of silicon metal. Power costs represent approximately one-third of operating costs for silicon producers. Subsequently, most new producers of silicon products have been where favorable electrical power availability and cost situations exist. Norway has traditionally been a major producer and exporter of silicon products because of its vast hydroelectric power resources. More recently, Brazil, China, and Venezuela have emerged as major exporters of silicon products largely because of their low power costs.

Operating Factors

Silicon metal is a raw material for the production of many silicone-base products, including silicone breast implants. Silicone-base products are

often used because they are considered nonreactive with other materials. However, silicone breast implants were being scrutinized for possible health problems caused by leakage and/or rupture. After being on the market for 30 years, use of silicone implants has been seriously questioned. Doctors have reported that implant patients have a variety of symptoms suspected to be caused by silicone gel leaks. Complaints reportedly began to surface about the safety of the devices in the early 1980's. The complaints alleged that leaky and/or ruptured implants were possibly contributing to an increased incidence of autoimmune diseases such as rheumatoid arthritis, lupus, and scleroderma (hardening of the skin) in implant patients.

Silicone breast implants were first introduced in the United States in the early 1960's. At that time, the Food and Drug Administration (FDA) had no authority to regulate medical devices. Congress granted the FDA authority to regulate medical devices in 1976; however, those medical devices already on the market were grandfathered under the law with the provision that FDA had the power to ask for safety data. In 1990, FDA reportedly started requesting that manufacturers file for formal approval. Manufacturers had until July 1991 to supply data showing that their devices were safe and effective.

In November 1991, an FDA advisory panel found the data submitted by the manufacturers to be insufficient to establish the safety of the implants. However, the panel recommended that the manufacturers be given more time to collect additional safety information under an FDA-imposed deadline. Additionally, the panel recommended that the implants be allowed to remain on the market during this period under certain restrictions. FDA estimates on the number of women in the United States who have had silicone breast implants is as high as 1 million.

By yearend, the FDA reportedly was increasingly concerned about how long the implants last in the body, how often they may leak or rupture, and the

possible harmful effects to the body that could be caused by leakage of silicone from ruptured or damaged devices.

ANNUAL REVIEW

Legislation and Government Programs

The U.S. Department of Commerce (DOC) and U.S. International Trade Commission concluded their investigations of silicon metal imports from Argentina, Brazil, and China. Domestic producers of silicon metal had filed for antidumping and countervailing duties against imports of silicon metal from these countries. The Agencies determined that silicon metal imports from these countries were sold at less than fair value and caused material harm to the domestic industry. Subsequently, dumping tariffs were levied against imports from the respective countries. The DOC assessed the dumping duty for Argentina at 8.65% and China at 139.49%. Duties for Brazilian imports were assessed against individual producers over a range of 87.79% to 93.2%. Silicon metal imports from Brazil and China dropped substantially following the determinations.

The Department of Energy reports that Federal funding appropriated for photovoltaic research amounted to \$46.1 million in 1991 compared with \$34.3 million in 1990.

Strategic Considerations

High-purity silicon is a strategic element of advanced electronic systems for commercial and military applications. Although the United States is a leader in the development of these systems, many of the components and devices within these systems are provided from foreign sources. Recent studies indicate Japan leads the United States in world semiconductor chip production.

Production

Overall gross production of silicon products decreased 16% compared with that of 1990. Production of silicon metal

rose by 3%, while production of ferrosilicon and miscellaneous alloys declined by more than 20%. The most significant change occurred in the production of 50%-grade ferrosilicon, which was down by 28%. Overall shipments of silicon-containing products decreased by 8%. Producer stocks of silicon-containing materials decreased by 18% overall. Ferrous scrap used in the production of these products was estimated to be 180,000 tons.

Simetco Inc., Montgomery, AL, made plans to restart its third and final silicon metal furnace during the fourth quarter. The furnace reportedly had been idle since midyear 1989 owing to low silicon metal prices and increased imports.¹

Applied Industrial Materials Corp. (AIMCOR) announced that the company had merged the management of its metals and minerals activities into one Pittsburgh-based office. AIMCOR's minerals unit relocated from the company's headquarters in Deerfield, IL.² In November, the United Steelworkers Union ended a 4-week strike at AIMCOR's Bridgeport, AL, facility. During the strike, the plant's single ferrosilicon furnace was under a maintenance shutdown, and delivery commitments were made through inventory stocks. Following the settlement, the furnace was reported to have restarted.

In June, Elkem Metals Co. opened a new 3,716-square-meter research and development center near its Pittsburgh, PA, headquarters. Elkem Metals, the U.S. subsidiary of Norwegian aluminum and ferroalloys producer Elkem AS, is the largest producer of bulk ferroalloys in the United States. Elkem's product line includes silicon-containing alloys as well as silicon metal. The new \$4.1 million facility replaces the company's aging research center in Niagara Falls, NY, which had operated for more than 50 years. The focus of the research at the new operation reportedly will be the development of new alloys and the improvement of existing products to meet the changing needs of the company's primary customers—the aluminum, chemical, and iron and steel industries.

The center planned to employ about 40 people when fully staffed.³

Union Carbide Chemicals and Plastics Co., Danbury, CT, acquired McGhan NuSil Corp., Carpinteria, CA, a developer and manufacturer of silicone materials for advanced technology applications. NuSil's products are used in medical, aerospace, defense, and electronic applications. The acquisition reportedly expanded Carbide's business in specialized organosilicone polymers, elastomers, gels, and resins for high-tech markets.⁴

Dow Corning Corp., Midland, MI, reportedly signed an agreement with Himont Inc., Wilmington, DE, to jointly develop and produce improved silane catalyst for polyolefin production. Dow is a major producer of silicon-base products, including silanes, while Himont is a producer of polypropylene resins, alloys, and advanced materials. Under the agreement, Himont expects improvement in catalyst technology that will boost the performance of its current catalyst. The agreement also creates marketing opportunities for Dow Corning.⁵

Dow Corning also announced plans for a \$262 million expansion at its silicones manufacturing complex in Barry, Wales. The investment program was expected to incorporate the latest silicone technology and reportedly more than double the plant's manufacturing capabilities for silicone intermediates. Dow's program to increase capacity reportedly is due to the favorable outlook for the silicones market.⁶ Completion of the expansion is expected in 1995.

In addition, Dow Corning was reported to be building a silicones facility at Lat Krabong, northeast of Bangkok. When completed, the facility would be operated by Dow Corning Thailand and would produce silicone rubbers, emulsions, and sealants.⁷

GE Silicones, the silicone products division of General Electric, reportedly plans to expand capacity at its silicone production facility in Waterford, NY. Work was scheduled for completion by the first quarter 1993. The expansion was part of a reported \$53 million

program that included the addition of an applications development center in Japan.⁸

Consumption and Uses

Apparent consumption of silicon-containing ferroalloys and silicon metal was estimated to be about 500,000 tons of contained silicon. Consumption of silicon metal was estimated at 175,000 tons, while consumption of ferrosilicon and miscellaneous silicon alloys was estimated to be about 325,000 tons. Compared with that of 1990, consumption of silicon metal decreased 10%, and consumption of ferrosilicon and other alloys decreased 17%. Ferrosilicon and miscellaneous silicon alloys accounted for about two-thirds of all the silicon materials consumed, based on silicon content.

The aluminum industry used silicon metal in the production of wrought and cast products, while ferrosilicon was used primarily as a deoxidizing and alloying agent in the production of iron and steel products. Metallurgical-grade silicon metal was also used as the basic raw material in the manufacturing of many chemical products and intermediates such as silicones and silanes. Silanes were used in the production of high-purity silicon for semiconductor devices, solar cells (photovoltaic cells), and infrared detectors. The U.S. Bureau of Mines did not collect data on electronic grades of silicon. (See table 3.)

Markets and Prices

Table 4 shows the average annual import price for 50%- and 75%-grade ferrosilicon as well as silicon metal. Prices are posted in cents per pound of contained silicon. The price for ferrosilicon continued the downward trend that started in 1989, as supply exceeded demand, forcing prices down. The import price for 50%-grade ferrosilicon started the year at 37.5 to 38.5 cents per pound, with a May high of 40.0 to 42.0, then fell steadily to a low of 35.0 to 36.0 by yearend. The import price for 75%-grade ferrosilicon followed a similar curve, starting the year at 36.0

to 36.5 cents per pound, peaking in May at 39.5 to 40.5, then falling thereafter to a low of 31.8 to 32.3 by yearend. Silicon metal prices improved for the year in the wake of DOC's assessment of antidumping duties for Brazil and China. The import price for silicon metal started the year at 54.0 to 57.0 cents per pound, peaked in early August at 66.0 to 66.5, then fell to 58.5 to 59.5 by yearend.

Foreign Trade

U.S. exports of ferrosilicon were relatively unchanged in 1991 compared with those of 1990, based on gross weight. (See table 6.) The total value of ferrosilicon exports decreased by 2%. More than 40% of the exported material was shipped to Canada. Silicon metal exports decreased by 8% based on gross weight, while the total value of the exports increased by more than 20%. More than 50% of the silicon metal exported was shipped to Canada, Japan, and Mexico.

U.S. imports of silicon-containing alloys decreased significantly compared with those in 1990. Imports of ferrosilicon categorized as "55% to 80% silicon, other" decreased 14% based on gross weight, with the total value for this category decreasing by 16%. A substantial decrease occurred in ferrosilicon categorized as "Other," which included all ferrosilicon of less than 55% silicon content. Imports of "Other" ferrosilicon decreased 35% based on gross weight and 44% by total value. Overall imports of silicon metal products decreased 35% based on gross weight and 12% by total value. Imports of silicon metal categorized as "99.00 to 99.99% silicon" decreased by more than 50% based on gross weight and almost 40% by total value. Imports from Brazil and China for this category were down dramatically, owing in part to dumping tariffs levied against the two countries. The U.S. net import reliance for ferrosilicon and silicon metal products were estimated to be 33% and 17%, respectively, compared with 30% and 27% the previous year. The overall

import reliance for silicon products was estimated to be 27%.

World Review

Capacity.—The data in table 8 are furnace capacity for the production of silicon-containing ferroalloys and silicon metal. Capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgement of the author, can be brought into production within a short period of time with minimum capital expenditure. Capacity is based on published reports, maximum production statistics, and estimates where capacity information is either incomplete or unavailable.

Australia.—Pioneer Silicon Industries Pty. Ltd. announced plans to close its Electrona silicon metal facility in southern Tasmania in August. However, (See tables 5 and 7.) the facility was to be kept on a care-and-maintenance basis pending review of the global silicon metal market. The single-furnace plant was reported to have capacity to produce approximately 10,000 metric tons per year (mt/yr) of silicon metal. Material produced at the facility was sold primarily to Asian markets.⁹

Brazil.—Cia. Brasileira Carbureto de Cálcio (CBCC) reportedly halted silicon metal production at its Santos Dumont plant for several months following the U.S. DOC's preliminary decision to retroactively impose a dumping tariff on silicon metal imports from Brazil. DOC's final decision in July imposed an 87.79% dumping tariff on CBCC, but was not retroactive. Subsequently, CBCC reportedly restarted silicon metal production at one of the facility's two furnaces.

Eletrivale S/A Indústria e Comércio reportedly was scheduled to complete construction of a 30-megawatt (MW) ferrosilicon furnace facility by the end of the year. The furnace was originally scheduled for completion in July. The new furnace will produce 75%-grade ferrosilicon and will add an additional 21,000 mt/yr to the company's existing 24,000-mt/yr ferrosilicon production capacity.¹⁰

In May, Cia. de Ferro Ligas da Bahia (Ferbasa) reportedly had reactivated one of its three idled ferrosilicon furnaces. One furnace was shut down in October 1990, and the other two furnaces had been idle since March. The combined production capacity for the three furnaces is reported to be 45,000 mt/yr.

Anuário da Indústria Brasileira de Ferroligas (ABRAFE), the Brazilian ferroalloy producers association, reported 1991 production as follows: 45%-grade ferrosilicon, 5,486 tons; 75%-grade ferrosilicon, 185,937 tons; calcium-silicon, 21,708 tons; and silicon metal, 106,002 tons. ABRAFE reported 1991 exports as follows: 45% (50%)-grade ferrosilicon, 13,853 tons; 75%-grade ferrosilicon, 141,226 tons; calcium-silicon, 19,328 tons; and silicon metal, 85,863 tons.

Bhutan.—Elkem Technology Norway and Elkem Engineering India reportedly was contracted to supply equipment for the 15,000-mt/yr ferrosilicon plant planned for construction by Bhutan Ferroalloys Ltd. The contract is said to be valued at about \$17 million. Supplies to be provided under the contract include furnace equipment and equipment for the handling of raw material and for pollution control.¹¹

Canada.—In May, Timminco Metals halted ferrosilicon production at its Beauharnois, Quebec, plant. The company had been operating only one of its two furnaces prior to the shutdown. Timminco was producing ferrosilicon for use at its magnesium operations and for outside sales.¹²

Metallurgie Silicium Echo International (MSEI), a subsidiary of Spain's Echevaria Group, made plans to construct a 28,000-mt/yr silicon metal plant at Amqui, Quebec. Metallurgie reportedly signed a tentative agreement to purchase power for the 40-MW two-furnace facility. The facility was scheduled for operation by November 1992. However, the plan required Government approval, and construction of the facility was not definite.¹²

Late in the year, Dow Corning indicated plans for the completion of its 6-MW silicon metal pilot plant in Manitoba. Completion of construction was scheduled for December with production to commence in January 1992. The plant will produce 2,000 to 3,000 mt/yr of silicon metal. The company is expected to make a decision in 1993 regarding the construction of a commercial-size facility.¹³

China.—An investigation by the U.S. International Trade Commission and the U.S. DOC found that silicon metal imports from China had been sold at less-than-fair market value and had caused material harm to the U.S. silicon metal industry. Subsequently, DOC assessed an antidumping duty of 139.49% on silicon metal imports from China. U.S. imports of silicon metal from China in 1991 decreased dramatically from that of the previous year.

In an apparent effort to raise ferrosilicon prices, the Chinese Government restricted the issue of ferrosilicon export licenses to three major companies: Minmetals, the China Metallurgical Import and Export Corp., and the China National Non-Ferrous Import and Export Corp. In addition, the Government also revised the endorsement system for licenses. The new policy attempts to limit export sales by smaller producers and coordinate producers' prices.¹⁴ Exports of Chinese ferrosilicon in 1991 totaled about 320,000 tons, an alltime high, and were about 30% greater than exports in 1990.¹⁵

European Community (EC).—After concluding an investigation that began in November 1989, the European Commission took action against imports of ferrosilicon from Brazil. In February 1991, six Brazilian producers agreed to a minimum reference price for ferrosilicon. In May, the Commission set a 39% antidumping duty against Brazilian ferroalloy producers whose prices did not meet the minimum reference price. However, Rima Electrometalurgia and CBCC were excluded from the 39% duty. CBCC was not determined to be dumping, and an import duty for RIMA was set at 12.2%. Brazilian imports reportedly supplied 4% of the European market in 1990.¹⁶

The EC was also reported to be investigating the alleged dumping of ferrosilicon by Egypt and Poland. In addition, allegations that Chinese exporters were absorbing the antidumping duty imposed on Chinese silicon metal imports to the EC would be investigated. It was alleged that the import price of the metal fell after the imposition of the duty.

Hong Kong.—In August, it was reported that Mainland Metals and Minerals would commence production at its silicon metal facility in the near future. Production of up to 500 mt/yr of metal was anticipated.

India.—Owing to the competitiveness of the ferrosilicon market, some producers shifted to the production of other ferroalloys. Nava Bharat Ferroalloys Ltd. reportedly was operating only one of its three 16.5-megavolt-ampere furnaces for the production of ferrosilicon. One furnace had been converted from ferrosilicon production to the production of ferrochromium. The remaining furnace was converted for silicomanganese production. VBC Ferro Alloys Ltd. suspended ferrosilicon production and converted its 16.5-megavolt-ampere furnace for high-carbon ferrochromium production.¹⁷

Indonesia.—In January, PT Ferrotama Alloys was reported to have created a

new subsidiary, PT Indo Alloy Dutanusa, to construct a new 24,000-mt/yr ferrosilicon plant in South Sumatra. Full operation of the plant was expected by early 1993. Ferrotama operates an existing 10,000-mt/yr ferrosilicon plant near Jakarta.¹⁸

Japan.—It was reported in July that Japan Metals and Chemicals (JMC) had contracted to sell electric power at its Matsukawa 22,000-kilowatt powerplant. The plant supplies power to JMC's Minami-Iwate ferrosilicon facility. JMC's ferrosilicon production had been reduced, leaving the company with excess power for consumption.¹⁹

The TEX Report reported that imports of ferrosilicon into Japan totaled 470,600 tons. Chinese imports accounted for 232,000 tons of ferrosilicon imports, an alltime high. Imports of silicon metal into Japan were reported to be 136,103 tons, an alltime high. Silicon metal imports from China and Brazil totaled 68,913 tons and 30,899 tons, respectively.

Norway.—In October, it was reported that Elkem AS and Fesil KS were both planning to curtail their output of ferrosilicon products. The production cutbacks were attributed to poor market conditions, increased competition from Eastern European producers, and for the purpose of inventory adjustment. Overall, Elkem planned a 10,000-metric-ton reduction for its Norwegian operations at Salten, Thamshavn, Bjolvefossen, and Sauda.²⁰ Fesil planned for similar cutbacks at its five domestic ferrosilicon plants. One of Fesil reductions was a 6-week shutdown of the 75,000-mt/yr Rana Metall plant. Fesil's cutbacks would reduce its rated capacity of 275,000 mt/yr by about 40%.²¹

U.S.S.R.—In September, Elkem of Norway and SA des Minerais of Luxembourg reportedly signed a letter of intent to form a joint venture to supply technology, equipment, and services to the ferroalloys industry in the U.S.S.R. The joint venture, Elsumin, was to be

incorporated in Luxembourg. Elsumin was expected to have a branch in Moscow that by yearend would be fully operational.²²

OUTLOOK

Demand for silicon metal will continue to be driven by consumption in the aluminum and chemical industries. Consumption by these industries is expected to undergo slow growth during the next 5 years. The automotive sector will contribute to this growth through increased aluminum content within each vehicle, as automobile producers seek to make vehicles lighter and more fuel efficient. Within the chemical industry, silicon metal is used to produce a wide variety of silicone-base products and intermediates. The worldwide silicones business is expected to continue to grow at a rate of about 7% annually. Industry sources suggest that overall consumption of silicon metal will grow at about 5% annually for the near term.

Ferrosilicon is consumed primarily by the iron and steel industries. The industries use ferrosilicon for both deoxidation of molten metal and as an alloying agent. The outlook for steel is discussed in the annual report for "Iron and Steel." The International Iron and Steel Institute has predicted that consumption of steel by industrialized countries will decline by an average of 0.1% per year for the period 1985 to 1995. Thus, based on this forecast, domestic ferrosilicon consumption is expected to remain at or be somewhat lower than the current level for this period. Factors that could influence consumption of ferrosilicon by the steel industry include technological changes and trade agreements.

¹American Metal Market. V. 99, No. 85, May 3, 1991, pp. 2, 16.

²———. V. 99, No. 43, Mar. 6, 1991, p. 2.

³———. V. 99, No. 108, June 6, 1991, pp. 2, 4.

⁴Chemical & Engineering News. V. 69, No. 15, Apr. 15, 1991, p. 7.

⁵American Metal Market. V. 99, No. 135, July 17, 1991, pp. 4, 10.

⁶Chemical Week. V. 149, No. 12, Oct. 23, 1991, p. 7.

⁷———. V. 148, No. 5, Feb. 6, 1991, p. 5.

⁸Chemical & Engineering News. V. 69, No. 45, Nov. 11, 1991, p. 7.

⁹Metals Week. V. 62, No. 23, June 10, 1991, p. 1.

¹⁰The TEX Report. V. 23, No. 5466, Aug. 21, 1991, p. 1.

¹¹Metal Bulletin. No. 7601, July 25, 1991, p. 9.

¹²Metals Week. V. 62, No. 21, May 27, 1991, p. 7.

¹³———. V. 62, No. 47, Nov. 25, 1991, p. 6.

¹⁴Metals Price Report. No. 104, Apr. 24, 1991, p. 1.

¹⁵The TEX Report. V. 24, No. 5613, Apr. 3, 1992.

¹⁶Metals Price Report. No. 106, May 9, 1991, p. 7.

¹⁷Metal Bulletin. No. 7640, Dec. 12, 1991, p. 11.

¹⁸Metals Week. V. 62, No. 4, Jan. 28, 1991, p. 2.

¹⁹———. V. 62, No. 29, July 22, 1991, p. 2.

²⁰Metals Price Report. No. 129, Oct. 16, 1991, p. 2.

²¹———. No. 131, Oct. 30, 1991, p. 6.

²²Metal Bulletin. No. 7617, Sept. 23, 1991, p. 11.

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TABLE 1
PRODUCTION, SHIPMENTS, AND STOCKS OF SILVERY PIG IRON,
FERROSILICON, AND SILICON METAL IN THE UNITED STATES IN 1991

(Metric tons, gross weight, unless otherwise specified)

Material	Silicon content (percentage)		Producers' stocks, December 31, 1990	Gross production ¹	Net shipments	Producers' stocks, December 31, 1991
	Range	Typical				
Silvery pig iron	5-24	18	W	W	W	W
Ferrosilicon	25-55	48	69,119	230,019	212,157	44,591
Do.	56-95	76	21,673	101,549	88,676	22,085
Silicon metal (excluding semiconductor grades)	96-99	98	13,746	149,570	138,182	19,062
Miscellaneous silicon alloys (excluding silicomanganese)	32-65	—	17,645	61,022	63,225	14,286

W Withheld to avoid disclosing company proprietary data.

¹Ferrosilicon production includes material consumed in the production of miscellaneous silicon alloys.

TABLE 2
PRODUCERS OF SILICON ALLOYS AND/OR SILICON METAL IN THE
UNITED STATES IN 1991

Producer	Plant location	Product
Alabama Alloys Inc.	Dolomite, AL	FeSi.
American Alloys Inc.	New Haven, WV	FeSi and Si.
Applied Industrial Minerals Corp.	Bridgeport, AL	FeSi.
Dow Corning Corp.	Springfield, OR	Si.
Elkem Metals Co.	Alloy, WV	Si.
Do.	Ashtabula, OH	FeSi.
Globe Metallurgical Inc.	Beverly, OH	FeSi and Si.
Do.	Selma, AL	Si.
Keokuk Ferro-Sil Inc.	Keokuk, IA	FeSi and silvery pig iron.
Silicon Metaltech Inc.	Wenatchee, WA	Si.
Simetco Inc.	Montgomery, AL	Si.
SKW Alloys Inc.	Calvert City, KY	FeSi.
Do.	Niagara Falls, NY	FeSi and Si.

TABLE 3
REPORTED CONSUMPTION, BY MAJOR END USE, AND STOCKS OF SILICON ALLOYS
AND METAL IN THE UNITED STATES IN 1991¹

(Metric tons, gross weight, unless otherwise specified)

Silicon content (percent)	Silvery pig iron	Ferrosilicon ²				Silicon metal	Miscel- laneous silicon alloys ³	Silicon carbide ⁴
		25-55	56-70	71-80	81-95			
Range	5-24	25-55	56-70	71-80	81-95	96-99	—	63-70
Typical	18	48	65	76	85	98	48	64
End use								
Steel:								
Carbon	—	28,429	—	20,920	(⁵)	(⁵)	1,078	(⁵)
Stainless and heat- resisting	—	54,303	—	33,176	(⁵)	274	8	—
Other alloy	(⁵)	18,323	—	32,973	(⁵)	(⁵)	329	(⁵)
Tool	—	(⁵)	—	1,269	(⁵)	(⁵)	—	—
Unspecified	22	121	—	94	647	8,421	15	88
Total⁶	22	101,177	—	88,432	647	8,695	1,431	88
Cast irons	16,523	101,949	3,158	15,401	451	704	16,100	11,819
Superalloys	—	W	—	103	15	W	—	—
Alloys (excluding superalloy and alloy steel)	W	3,976	—	W	—	(⁵)	23	—
Miscellaneous and unspecified	11	1,515	—	396	—	⁷ 166,801	—	—
Grand total⁶	16,555	208,617	3,158	104,333	1,112	176,200	17,553	11,907
Consumers' stocks, December 31	1,100	6,094	134	3,944	38	2,082	994	626

W Withheld to avoid disclosing company proprietary data; included in "Miscellaneous and unspecified."

¹Includes U.S. Bureau of Mines estimates.

²Includes briquets.

³Primarily magnesium-ferrosilicon but also includes other silicon alloys.

⁴Does not include silicon carbide for abrasive or refractory uses.

⁵Included with "Steel: Unspecified."

⁶Data may not add to totals shown because of independent rounding.

⁷Includes silicones, silanes, fumed silica, and other chemicals.

TABLE 4
TIME-PRICE RELATIONSHIP FOR
SILICON PRODUCTS¹

(Cents per pound)

Year	Silicon metal	Ferrosilicon ²	
		50 percent	75 percent
1980	59.17	39.80	41.77
1981	61.04	41.54	40.01
1982	57.35	41.42	37.93
1983	53.77	37.12	36.67
1984	60.35	41.22	41.89
1985	58.77	37.52	35.71
1986	56.32	35.55	33.65
1987	58.06	38.51	36.78
1988	68.67	52.08	56.82
1989	58.75	49.57	48.96
1990	54.84	42.44	39.94
1991	61.50	38.34	36.98

¹U.S. dealer import price.

²Prices based on contained weight of silicon.

Source: Metals Week.

TABLE 5
HARMONIZED TARIFF SCHEDULE FOR SILICON PRODUCTS

Item	HTS No.	Rate of duty effective January 1, 1991	
		Most favored nation (MFN)	Non-MFN
Ferrosilicon, 55% to 80% Si:			
More than 3% Ca	7202.21.1000	1.1% ad valorem ^{1 2}	11.5% ad valorem.
Other	7202.21.5000	1.5% ad valorem ^{1 2}	Do.
Ferrosilicon, 80% to 90% Si	7202.21.7500	1.9% ad valorem ³	9.0% ad valorem.
Ferrosilicon, more than 90% Si	7202.21.9000	5.8% ad valorem ³	40.0% ad valorem.
Ferrosilicon, other:			
Ferrosilicon, more than 2% Mg	7202.29.0010	Free	4.4 cents per kilogram Si.
Ferrosilicon, other	7202.29.0050	do.	Do.
Silicon, more than 99.99% Si	2804.61.0000	3.7% ad valorem ^{4 5}	25.0% ad valorem.
Silicon, 99.00% to 99.99% Si	2804.69.1000	5.3% ad valorem ^{2 6 7}	21.0% ad valorem.
Silicon, other	2804.69.5000	9.0% ad valorem ^{4 8}	45.0% ad valorem.

¹Free from certain beneficiary countries under the Generalized System of Preferences (GSP), for products of Canada under the United States-Canada Free-Trade Agreement, from beneficiary countries under the Caribbean Basin Economic Recovery Act (CBERA), and for products of Israel under the United States-Israel Free Trade Area.

²Not duty free for Brazil.

³Free for products of Canada, from beneficiary countries under the CBERA, and for products of Israel.

⁴Free from beneficiary countries under the CBERA and for products of Israel.

⁵1.4% ad valorem for products of Canada.

⁶Free from certain beneficiary countries under the GSP, from beneficiary countries under the CBERA, and for products of Israel.

⁷3.7% ad valorem for products of Canada.

⁸6.3% ad valorem for products of Canada.

TABLE 6
U.S. EXPORTS OF FERROSILICON AND SILICON METAL, BY GRADE AND COUNTRY

(Metric tons)

Grade and country	1990			1991		
	Gross weight	Contained weight	Value (thousands)	Gross weight	Contained weight	Value (thousands)
Ferrosilicon:						
More than 55% silicon:						
Canada	4,485	2,691	\$5,365	5,196	3,118	\$5,471
Germany, Federal Republic of	905	534	776	771	473	888
Japan	377	241	394	723	434	515
Korea, Republic of	1,427	1,021	1,264	507	304	386
Mexico	6,666	4,025	5,670	5,893	3,622	5,241
Other	2,180	1,321	1,924	1,740	1,050	1,708
Total¹	16,039	9,833	15,392	14,831	9,001	14,209
Other ferrosilicon:						
Canada	14,025	7,012	10,912	15,893	7,946	11,270
Germany, Federal Republic of	2,245	1,122	1,773	2,960	1,469	2,730
Japan	1,335	667	1,242	2,361	1,184	2,332
Mexico	3,565	1,741	2,721	3,547	1,773	2,638
United Kingdom	5,832	2,896	4,735	5,149	2,574	4,138
Other	7,038	3,523	7,217	5,653	2,805	5,690
Total¹	34,040	16,962	28,600	35,563	17,751	28,798
Total ferrosilicon¹	50,079	26,794	43,993	50,393	26,752	43,008
Metal:						
More than 99.99% silicon:						
Denmark	51	51	3,965	61	61	5,224
Italy	143	143	8,396	99	99	4,835
Japan	504	504	27,894	1,020	1,020	52,995
Korea, Republic of	39	39	1,414	95	95	3,684
Malaysia	203	203	36,495	125	125	30,475
Other	119	119	3,014	111	111	5,630
Total¹	1,059	1,059	81,178	1,511	1,511	102,843
99.00% to 99.99% silicon:						
Ghana	105	104	132	220	218	282
Hong Kong	—	—	—	60	59	84
Mexico	377	374	507	202	200	278
South Africa, Republic of	326	323	371	159	158	192
Venezuela	1,171	1,161	1,515	582	577	828
Other	1,124	1,114	1,313	231	229	350
Total¹	3,103	3,077	3,837	1,454	1,441	2,014
Other silicon:						
Canada	453	440	588	1,092	1,061	1,438
Hong Kong	3	3	5	457	443	621
Japan	290	285	587	864	839	1,173
Korea, Republic of	168	163	312	664	642	984
Mexico	1,756	1,696	2,400	1,067	1,036	1,426

See footnotes at end of table.

TABLE 6—Continued
U.S. EXPORTS OF FERROSILICON AND SILICON METAL, BY GRADE AND COUNTRY

(Metric tons)

Grade and country	1990			1991		
	Gross weight	Contained weight	Value (thousands)	Gross weight	Contained weight	Value (thousands)
Other silicon—Continued						
Other	2,148	2,068	\$3,321	1,136	1,103	\$1,822
Total¹	4,818	4,655	7,214	5,281	5,125	7,465
Total silicon metal¹	8,980	8,791	92,229	8,246	8,077	112,323

¹Revised.

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 7
U.S. IMPORTS FOR CONSUMPTION OF FERROSILICON AND SILICON
METAL, BY GRADE AND COUNTRY

(Metric tons)

Grade and country	1990			1991		
	Gross weight	Contained weight	Value (thousands)	Gross weight	Contained weight	Value (thousands)
Ferrosilicon:						
55% to 80% silicon, more than 3% Ca:						
Argentina	1,644	999	\$1,563	288	175	\$273
Brazil	14,978	9,425	18,484	5,339	3,596	5,037
Canada	—	—	—	253	185	181
China	257	146	266	70	40	74
France	2,659	1,591	4,358	1,939	1,175	2,767
Germany, Federal Republic of	1	1	2	—	—	—
Italy	1,992	1,216	2,565	339	210	409
Norway	—	—	—	5,400	4,076	3,023
United Kingdom	—	—	—	72	41	71
Venezuela	567	425	655	—	—	—
Total¹	22,099	13,802	27,893	13,700	9,498	11,836
55% to 80% silicon, other:						
Argentina	9,164	6,832	5,001	6,406	4,811	3,105
Australia	1,246	881	263	—	—	—
Brazil	42,635	31,897	24,775	21,174	15,761	9,953
Canada	18,089	13,694	10,668	11,843	8,934	7,323
China	4,074	2,985	1,703	3,773	2,837	1,948
Egypt	6,182	4,018	2,871	—	—	—
France	500	326	731	371	242	686
Germany, Federal Republic of	618	439	1,704	302	227	991
Japan	215	144	615	23	17	27
Mexico	61	42	179	11	9	52
Norway	26,256	19,600	14,506	26,622	20,023	15,776
United Kingdom	—	—	—	11,137	8,378	5,900
Venezuela	30,859	22,889	14,436	40,556	29,910	20,074
Yugoslavia	1,000	680	407	—	—	—
Zimbabwe	551	358	158	—	—	—
Total¹	141,450	104,786	78,017	122,218	91,148	65,835
80% to 90% ferrosilicon:						
Canada	—	—	—	69	59	28
More than 90% silicon:						
Brazil	100	94	59	—	—	—
Magnesium ferrosilicon:						
Brazil	582	260	255	210	99	130
Canada	3,039	539	1,587	19	3	8
China	134	47	213	—	—	—
France	105	57	138	72	23	84
Germany, Federal Republic of	446	240	1,572	412	214	1,253
Japan	108	48	222	105	45	217

See footnotes at end of table.

TABLE 7—Continued
**U.S. IMPORTS FOR CONSUMPTION OF FERROSILICON AND SILICON
 METAL, BY GRADE AND COUNTRY**

(Metric tons)

Grade and country	1990			1991		
	Gross weight	Contained weight	Value (thousands)	Gross weight	Contained weight	Value (thousands)
Ferrosilicon-Continued						
Magnesium-Continued						
Norway	—	—	—	42	20	\$15
Total ¹	4,415	1,191	\$3,987	860	404	1,707
Other ferrosilicon:						
Brazil	9,338	3,926	3,480	5,252	2,024	917
Canada	16,660	6,532	5,900	7,024	1,826	2,210
China	67	24	86	250	96	226
Egypt	978	460	205	—	—	—
France	83	34	137	16	8	24
Germany, Federal Republic of	—	—	—	142	21	179
Japan	49	23	99	—	—	—
Netherlands	—	—	—	16	2	20
Norway	1,300	663	670	—	—	—
U.S.S.R.	41,445	19,596	14,113	33,666	16,066	10,472
Venezuela	900	433	286	—	—	—
Zimbabwe	100	42	63	—	—	—
Total ¹	70,920	31,733	25,038	46,367	20,044	14,049
Total ferrosilicon ¹	238,983	151,605	134,993	183,214	121,153	93,455
Metal:						
More than 99.99% silicon:						
Belgium	(²)	(²)	2	—	—	—
Brazil	3	3	156	—	—	—
China	—	—	—	1	1	15
Czechoslovakia	—	—	—	1	1	173
Denmark	6	6	401	2	2	457
France	18	18	984	14	14	842
Germany, Federal Republic of	418	418	20,646	316	316	13,282
Ireland	1	1	45	(²)	(²)	77
Italy	170	170	28,427	203	203	32,012
Japan	90	90	2,138	261	261	6,520
Korea, Republic of	3	3	386	11	11	54
Malaysia	(²)	(²)	49	(²)	(²)	13
Poland	(²)	(²)	6	1	1	144
Sweden	(²)	(²)	1	—	—	—
Switzerland	(²)	(²)	1	(²)	(²)	2
Taiwan	(²)	(²)	7	(²)	(²)	4
U.S.S.R.	(²)	(²)	17	(²)	(²)	15
United Kingdom	(²)	(²)	17	(²)	(²)	1
Total ¹	709	709	53,284	811	811	53,613
99.00% to 99.99% silicon:						
Argentina	2,140	2,119	2,083	4,676	4,634	5,169
Australia	395	384	362	7,045	6,972	8,255
Brazil	24,367	24,160	23,363	2,150	2,133	2,160
Canada	7,105	7,028	8,945	7,333	7,277	9,864

See footnotes at end of table.

TABLE 7—Continued
**U.S. IMPORTS FOR CONSUMPTION OF FERROSILICON AND SILICON
 METAL, BY GRADE AND COUNTRY**

(Metric tons)

Grade and country	1990			1991		
	Gross weight	Contained weight	Value (thousands)	Gross weight	Contained weight	Value (thousands)
Metal—Continued						
99% to 99.99% silicon—Continued						
China	19,292	19,126	\$15,546	1,819	1,807	\$1,391
Czechoslovakia	—	—	—	(²)	(²)	17
Denmark	20	20	26	—	—	—
France	355	352	438	1,620	1,607	1,934
Germany, Federal Republic of	22	22	36	1,600	1,585	1,963
Hong Kong	1,492	1,475	1,267	20	20	17
Japan	19	19	20	—	—	—
Korea, Republic of	2	1	5	1	1	3
Norway	—	—	—	1,035	1,027	1,295
Portugal	—	—	—	67	67	51
South Africa, Republic of	270	267	303	600	594	736
Spain	—	—	—	96	95	108
Sweden	16	16	50	1	1	8
Switzerland	201	199	162	—	—	—
Taiwan	134	133	102	—	—	—
Yugoslavia	1,309	1,296	1,274	—	—	—
Total¹	57,139	56,617	53,982	28,062	27,821	32,970
Other silicon:						
Argentina	20	20	15	415	408	403
Australia	60	44	69	—	—	—
Belgium	3	2	23	—	—	—
Brazil	4,738	4,611	3,830	6,147	6,052	5,645
Canada	626	616	586	200	197	241
China	2,648	2,599	2,185	1,376	1,326	1,196
France	8	8	14	171	169	315
Germany, Federal Republic of	10	10	13	—	—	—
Greece	—	—	—	180	176	175
Hong Kong	368	363	294	—	—	—
Italy	2	2	10	155	155	20
Japan	36	35	60	—	—	—
Sweden	—	—	—	1	1	6
United Kingdom	5	5	6	—	—	—
Venezuela	12	11	13	—	—	—
Yugoslavia	—	—	—	5,868	5,774	5,789
Total¹	8,534	8,325	7,119	14,513	14,257	13,790
Total silicon metal¹	66,383	65,651	114,385	43,386	42,888	100,373

¹Data may not add to totals shown because of independent rounding.

²Less than 1/2 unit.

Source: Bureau of the Census.

**TABLE 8
WORLD PRODUCTION
CAPACITY FOR
SILICON-CONTAINING
FERROALLOYS AND SILICON
METAL IN 1990**

(Thousand metric tons, contained silicon)

Country	Capacity
Argentina	37
Australia	58
Brazil	407
Bulgaria	()
Canada	94
Chile	7
China	830
Colombia	()
Czechoslovakia	()
Egypt	45
France	152
Germany, Federal Republic of:	
Eastern states	()
Western states	60
Hungary	()
Iceland	50
India	60
Italy	95
Japan	82
Korea, North	()
Korea, Republic of	18
Mexico	17
Norway	418
Peru	()
Philippines	18
Poland	()
Portugal	12
Romania	()
South Africa, Republic of	105
Spain	69
Sweden	38
Switzerland	()
Taiwan	10
U.S.S.R.	980
United States	468
Uruguay	()
Venezuela	48
Yugoslavia	135
Other	240
Total	4,553

¹Included with "Other."

SILVER

By Robert G. Reese

Mr. Reese, a physical scientist with the Branch of Metals, has been the commodity specialist for silver for 10 years. Domestic survey data were prepared by Lisa Conley and Dwayne Penn, mineral data assistants; and international data tables were prepared by Virginia Woodson, international data coordinator.

Domestic silver production decreased for the first time in 5 years. A number of mines, including both primary and byproduct silver producers, either reduced their level of operation or ceased mining entirely. The domestic economic recession and low prices for silver and some other metals were cited by company officials when discussing their decisions regarding production levels.

The Government continued to reduce its silver holdings. The Bureau of the Mint produced three commemorative coins during the year. The National Defense Stockpile (NDS) was the source of the silver used in the three coin series.

The average annual domestic silver price fell for the fourth consecutive year. The low price for the year as quoted by Handy and Harman was the lowest daily price since January 1974. Analysts attributed the continued weak price to a lack of investor demand combined with a drop in industrial demand.

The domestic apparent demand for refined silver was 3,846 metric tons in 1991. Apparent demand measures both the quantity of silver required by domestic manufacturers and the quantity of silver demanded by U.S. investors. The decrease in apparent demand was attributed primarily to the domestic recession and a lack of investor demand. An estimate of domestic consumption derived by the CPM Group for the Silver Institute was published in mid-1992. According to analysts at CPM, domestic silver consumption in 1991 was lower than that in the previous year.

DOMESTIC DATA COVERAGE

Domestic mine production data for silver were developed by the U.S. Bureau of Mines from four separate, voluntary surveys of U.S. operations. Typical of these surveys was the lode mine production survey of copper, gold, lead, silver, and zinc. Of the 141 silver-producing lode mines to which a survey form was sent, 129 responded, accounting for an estimated 94% of the total U.S. mine production shown in tables 1, 2, 3, 5, 6, and 7.

BACKGROUND

Silver has played an important role in peoples' lives since ancient times. Early people used silver for ornaments and utensils and as a substance that could be bartered for other goods and services. This concept of the "value" of silver eventually led to its use as the standard in monetary systems, such as that of the Roman Empire, and as a means of paying for international trade. Silver continued to be the standard for most currencies until the discovery of major silver deposits in Mexico and Peru. As more silver deposits were discovered in the 18th and 19th centuries, countries gradually abandoned silver as the standard for their currencies in favor of a gold standard.

Expanding industrial use of silver eventually led to the elimination of silver in U.S. coinage. In the early 1960's, the U.S. Department of the Treasury became a major supplier of silver to industrial consumers. The Treasury, however, had insufficient stocks both to meet industrial

demand and to maintain an adequate supply of circulating silver coinage for a prolonged period. When the silver price reached \$1.29 per ounce, the value of the silver in a silver dollar equaled \$1 in currency. At silver prices greater than \$1.29, the silver in a silver dollar would have been worth more than \$1 in currency, and as a result, it could have been advantageous to melt silver dollars for their silver content, thereby decreasing the amount of circulating coinage. Similarly, if the silver price rose above \$1.38 per ounce, the silver in dimes, quarters, and half-dollars would have been worth more than the coins' face value. To avoid a possible meltdown of the circulating coinage, the Treasury attempted to control the silver price through increased silver sales and increased minting operations from 1964 to 1967. A reduced silver content half-dollar, along with silverless dimes and quarters, were introduced in 1965 to help maintain the supply of circulating coinage, and in 1967, the Treasury announced that all silver coins were being withdrawn from circulation.

Silver occurs as native metal, but is usually found combined with sulfur. Until the 16th century, the ratio of silver to gold produced in Europe was about 10:1. Most of the silver was obtained from the lead sulfide ore galena. With the discovery and exploitation in the 16th and 17th centuries of silver deposits in the Americas, silver production shifted away from Europe. As production increased in Bolivia, Mexico, and Peru, the world ratio of silver to gold production increased because silver was relatively more abundant than gold in the New

World. Following the 1859 discovery of the Comstock Lode in Nevada, the United States was the world's leading silver producer from 1871 to about 1900. Mexico was the leading producer from 1900 to 1968, yielding to Canada from 1968 to 1976. In 1976, Mexico regained the position of the world's leading silver producer, a position that it held through 1991.

Definitions, Grades, and Specifications

The purity of silver in bullion, coinage, jewelry, or other items is usually expressed by its "fineness," or parts per thousand. Pure, or "fine," silver is 1,000 parts fine or 100.0% silver. Sterling silver is 925 fine, or 925 parts (92.5%) silver and 75 parts (7.5%) copper. Domestic coin silver is an alloy that was used in minting coinage until 1964 and contained 900 parts silver and 100 parts copper. Commercial silver bullion ranges from 999 to 999.9 fine. For any fineness of silver bullion, the principal impurities are gold or copper. Doré silver is unrefined silver bullion generally containing a variable percentage of gold as an impurity. Silver for the NDS is required to be 999 fine; free of slag, dirt, or other foreign material; and in bars weighing approximately 31 kilograms.

Uses and Products for Trade and Industry

The most important use of silver is in photographic materials. Silver is used in the manufacture of film, photographic paper, photocopying paper, X-ray film, photo-offset printing plates, and in some other minor light-sensitive products. Photographic materials are produced by depositing thin layers of silver salts, gelatin, and dyes onto a support material. Silver salts, although not extremely sensitive to light when first exposed to illumination, produce a greatly intensified image when subsequently treated with photographic chemical developers. The developer reduces a portion of each silver salt grain to metallic silver, depending on the intensity of the light to which the

grain was exposed. The resulting gray to black metallic silver forms a negative image of the original object.

Silver is used in electrical and electronic products because of its high electrical and thermal conductivity and its resistance to corrosion. Silver has the highest thermal and electrical conductivities of any metal. Silver, in general, can be characterized as strongly resistant to atmospheric and ordinary oxidation and exceptionally resistant to corrosion by weak acids. Although silver commonly reacts with sulfur-containing atmospheric gases to form a sulfide tarnish, the tarnish itself offers little electrical resistance and does not prevent the use of silver as an electrical contact material. Pure silver is generally used in low- and medium-current switching devices. In other applications where the device requires higher strength, more wear resistance, better resistance to arcing, or lower costs, silver is usually alloyed with another metal such as copper or palladium to produce the desired characteristics.

Batteries constitute another electrical use for silver. Silver batteries produce a high-energy output per unit size and weight, but are generally characterized by a short life and high per unit cost. Primarily because of the short life and high costs, the use of silver batteries has been confined to defense and space applications where battery weight, size, and reliability are major concerns. There is, however, a growing use for small silver-zinc button cells in such commercial applications as calculators and hearing aids.

The use of silver for decorative purposes can be divided into three main applications. Probably the oldest use of silver is its use in jewelry. Silver or a silver alloy, usually silver and copper, is flattened and shaped into objects that can be worn for personal adornment. Sterlingware, the second decorative use, consists of articles such as bowls and flatware that are often functional as well as decorative. Sterling silver is an alloy of silver (92.5%) and copper (7.5%). The third decorative use for silver is electroplated ware. Electroplated ware

generally consists of the same types of objects produced as sterlingware, the difference being that electroplated ware is made by depositing a thin silver layer on a base metal object, whereas the sterlingware object is formed entirely of the silver-copper alloy. Because less silver is used in a piece of electroplated ware than is used in a similar piece of sterlingware, the price of the plated piece is less than the price of a corresponding sterlingware piece.

The refrigeration and air-conditioning industry uses silver in the form of brazing alloys because of the ability of silver brazing alloys to wet various base metals at temperatures below their melting points. In general, silver brazing alloys do not dissolve or attack steel in normal usage, are ductile, maintain their strength over a wide range of temperatures, and will join a variety of materials. Silver is added to some solders to improve their flow properties, corrosion resistance, and wettability.

Silver is also used in mirrors, catalysts, medicinals, dental amalgams, bearings, coins, medallions, and a variety of commemorative objects. Silver is used in mirrors because of its high reflectivity in the visible portion of the spectrum. Silver catalysts are used in oxidation reactions such as the production of formaldehyde from methanol and the conversion of ethylene to ethylene oxide. Medicinal compounds include the soluble salts, such as the nitrates and citrates, and insoluble compounds such as the oxides, halides, and proteinate. In dentistry, silver is an important component of amalgam fillings.

Refined silver is available in the form of bars, grain, sheet, strip and foil, wire, rod and tubing, powder, and flake. Bars produced at refineries generally weigh about 31 kilograms and are about 30.5 centimeters long by 12.7 centimeters wide and 10.2 centimeters thick. Grain silver is produced by pouring molten silver into water, creating irregularly shaped silver particles less than 1.3 centimeters across. Silver sheet and foil are available in widths of up to almost 2.1 meters and as thin as 0.01 millimeter. Generally, the thinner the sheet or foil, the narrower it

is in width. Silver rod and wire can range from 5 centimeters in diameter to 0.1 millimeter in diameter. Openings in silver tubing can range from capillary size through 15 centimeters in diameter. Silver powders are generally powder-size (0.5 to 2 micrometers) spherical particles, although coarsensized particles can be produced.

Geology-Resources

About two-thirds of the world silver reserves and resources is contained in copper, lead, and zinc deposits. Ores in which silver or gold is the main component account for the remaining one-third of total world reserves and resources. U.S. silver resources are estimated to be about 190,000 tons.¹ Total world silver resources are estimated to be about 780,000 tons.

The chief silver minerals found in U.S. reserves are native silver (Ag), argentite (Ag₂S), cerargyrite (AgCl), polybasite (Ag₁₆Sb₂S₁₁), proustite (Ag₃AsS₃), pyrargyrite (Ag₃SbS₄) and tetrahedrite (Cu₃(Sb, As)S₃). Other ore minerals of silver are the tellurides, stromeyerite, and pearceite.

U.S. silver reserves are usually found associated with intermediate felsic rocks such as andesites and rhyolites, in veins ranging from a few centimeters to several meters in width. Ores from which silver is produced as a byproduct are usually found in copper porphyries, massive sulfide deposits, or in copper-lead-zinc vein deposits. Historically, most of the U.S. silver production has been from the Rocky Mountain States. It is likely that if major new reserves are discovered, the deposits will be in this region.

Technology

Mining.—Silver is mined using well-established open pit and underground methods. Open pit mining consists of removing overburden, drilling and blasting the exposed ore, loading the broken ore, and hauling the ore to the processing plant. Overburden removal is done with draglines or bulldozers, depending on the depth of the ore body.

The broken ore is loaded by either power shovels or front-end loaders, and the ore is shipped to the processing plant by truck, train, conveyor belt, or some combination of these transport modes, depending on the distance to the plant.

Underground mining of silver is generally done using one of several stope mining methods. Stope mining consists of the development of a series of horizontal workings, or stopes, into the ore body from a shaft or tunnel. The stopes are above each other and can be vertically separated by as much as 60 meters of ore. The ore between the stopes is removed through the use of explosives.

Beneficiation.—Current treatment of silver-containing base metal ores is almost entirely by a flotation process. The concentrates contain the silver along with the copper, lead, and zinc. The silver is recovered from intermediate products resulting from smelting the concentrates. In predominantly lead ores, silver is carried down with the lead in smelting and separated from it by the addition of zinc to the molten silver-lead mixture. The mixture is allowed to cool, and the virtually insoluble silver-zinc alloy separates from the molten lead and rises to the surface where it is skimmed. In addition to the silver, this first crust contains some lead and any gold contained in the original ore. The zinc is distilled in a retort for reuse. The retort residue is roasted to recover the gold and silver as doré metal and the lead as litharge.

In predominantly copper ores, the silver is carried down with the copper in smelting. In the electrolytic refining of copper, the silver accumulates in the anode slime, from which it is recovered as silver bullion by smelting.

Gold and silver ores are generally treated by cyanidation. The ores are crushed by grinding in rod or ball mills and then leached with a dilute cyanide solution. Zinc dust is used to precipitate the gold and silver from the cyanide solution. The precipitate is melted in a furnace to produce a doré metal.

Silver bullion is generally refined using an electrolytic process. In the process, electricity is applied to a standard electrolytic cell in which the impure silver bullion is used as the anode, silver nitrate and nitric acid is used as the electrolyte, and either a pure silver strip or graphite is used as the cathode. Passage of an electrical current results in dissolution of silver in the anode and its subsequent deposition as silver crystals on the cathode. The silver crystals are periodically stripped from the cathode and collected, melted, and cast into bullion bars.

Economic Factors

Costs of mining silver ores vary greatly with depth, ground control problems, ventilation, width of vein, continuity of ore bodies, location, presence of byproduct metals, and the availability of electricity, water, labor, and equipment. Low-grade deposits can usually be mined profitably if sufficient quantities of other metals are contained in the ore. Accurate information on capital costs is difficult to obtain, not only because of variability in the factors enumerated above, but because of differences in accounting methods and definitions used by the mining industry. In general, the cost of mining silver ranges from less than about \$30 per kilogram (\$1.00 per troy ounce) to more than \$260 per kilogram (\$8.00 per troy ounce). Underground mining is, in general, more expensive than surface mining.

U.S. tax laws permit silver-producing companies a depletion allowance of 15% for domestic operations and 14% for foreign operations. There are no tariffs on the importation of silver ores, concentrates, doré, scrap, or refined bullion. Tariffs on semimanufactured silver can be as high as 27.5% ad valorem for countries receiving most-favored-nation classification and can be as high as 110% ad valorem for imports from those countries classified as non-most-favored nation, depending on the item.

Operating Factors

Silver mining is, in general, no more hazardous than other mining, but because of the depths reached in the Coeur d'Alene district, rock bursts there are relatively common. Temperatures are uncomfortable at these depths, and air conditioning must be used in ventilation systems. Gains in productivity are difficult to achieve because the possibilities for mechanization are limited by the relatively narrow veins mined. In recent years, companies have attempted to increase productivity through modification of labor agreements to allow more flexibility in work assignments and compensation and by improved mining plans.

Although in most circumstances silver is not a toxic substance in other than very large doses, a standard has been established for worker exposure to airborne particulate silver. The Occupational Safety and Health Administration currently requires that the concentration of either silver metal or soluble silver compounds be less than 0.01 milligram per cubic meter of ambient air in workplaces.

Nearly all silver-bearing ores are processed after grinding by flotation or cyanidation. Pollution of downstream waters by fine solids from flotation plants is a problem that requires adequate ponding and retention of tailings. Disposal or stabilization of the accumulated tailings can be a problem at some mines. It can be partially solved in those deep mines where ground support is needed by pumping the tailings back into the mine. In cyanidation operations, extreme care must be exercised to avoid contamination of the ground water, nearby watercourses, or surrounding areas through losses of leach solution. As a result, the solution collection system for returning the leachant to the storage tanks and the system for monitoring water in the surrounding area must be adequate to prevent pollution.

Achieving adequate air pollution (sulfur dioxide) control and disposing of slag and other wastes (iron and silica) are the problems encountered in smelting

silver ores. Refining presents little environmental concern because the bulk of noxious impurities are removed during the smelting step; however, spent solutions from electrolytic refining present a disposal problem because of toxic materials in the solutions.

ANNUAL REVIEW

Legislation and Government Programs

The Bureau of the Mint produced three commemorative coins during the year. Public Law 101-332 authorized the production of gold, silver, and copper-nickel-clad coins in honor of the 50th anniversary of the Mount Rushmore National Memorial. Public Law 101-404 authorized the production of silver coins to commemorate the 50th anniversary of the United Services Organization (USO). Public Law 101-495 authorized the minting of a silver coin to commemorate the 38th anniversary of the ending of the Korean War.

All three silver commemorative coins had the same specifications. Each coin was made from a 90% silver-10% copper alloy, weighed 26.73 grams, and had a diameter of 3.8 centimeters. Inscribed on each coin was its face value (\$1.00) and the words "Liberty," "In God We Trust," "United States of America," and "E Pluribus Unum." Also included on the Mount Rushmore and USO commemorative coins was the year of production (1991). Inscribed on the Korean War coin though, was the time period, 1953-1991. All three coins were legal tender. The NDS was the source of the silver used to manufacture the three coins. The enabling legislation limited the number of coins to be issued to 2 million for the Mount Rushmore commemorative coin and 1 million each for the USO and Korean War coins.

Included in the sales price of each coin was its face value and the labor, materials, dies, machinery, and various expenses, including overhead, marketing, and shipping required to design and issue the coins. Also added to the price of each coin was a \$7.00 surcharge. Surcharges collected from the sale of the

Mount Rushmore coins were divided, with one-half used to reduce the National debt and one-half given to the Mount Rushmore National Memorial Society to improve, enlarge, and renovate the Mount Rushmore National Memorial. One-half of the surcharges collected from sales of USO coins went to reduction of the National debt and one-half to the USO to fund its various programs. The Korean War Veterans Memorial Fund received all the surcharges collected from sales of the Korean War commemorative coins. The fund was to provide for the construction and maintenance of a Korean War Veterans Memorial in Washington, DC.

Production

Silver was produced from precious-metal ores at 120 lode mines and from base metal ores at 21 lode mines. Silver was also produced at eight placer operations. In 1991, 17 mines each produced more than 30 tons of silver; their aggregated production equaled 75% of total domestic production.

In October, Magma Copper Co. signed an innovative labor agreement with its unions. The new agreement conditionally covered a 15-year period and prohibited strikes and lockouts for at least 7 years. Hourly workers were to receive wage increases of \$0.25 to \$0.35 per hour during the first 5 years of the agreement, with some increases tied to company earnings. After the initial 5-year period, the agreement would continue in force for another 10 years unless either party proposed to modify it. If the company and the unions could not agree on the proposed modifications, then the suggested modifications would be submitted to arbitration. After the initial 5 years, the use of arbitration twice in any subsequent 5-year period would terminate the contract. The termination would occur on the anniversary of the second arbitration award.

Alaska.—During the year, workers at the Greens Creek Mine mined and processed about 390,000 tons of ore and recovered almost 242 tons of silver.² As

in the previous year, reserves at the mine increased significantly. At yearend 1991, Greens Creek's estimated proven and probable reserves were about 12,560,000 tons grading 414 grams of silver per ton.

Performance improved at the Red Dog Mine following some mill modifications and as workers gained a better understanding of the various ore types. The operation processed almost 1,451,000 metric tons of ore in 1991 compared with 904,000 tons during the mine's first full year of operation. Average silver content of the ore was 87 grams per ton.³ The company solved an unanticipated mine drainage problem during the year. Although the natural drainage at Red Dog was acidic and contained high metal levels, mining operations at the site reportedly aggravated the situation. To solve the problem, Cominco spent U.S.\$14.0 million to divert the major water course in the area around the pit. The company also began to treat contaminated water generated in the pit and divert it to the tailings pond.

Arizona.—Magma Copper purchased the McCabe Mine during the year. The underground mine produced about 523 kilograms of silver and 121 kilograms of gold.⁴

In July, Magma signed a Memorandum of Commitment with its unions. The memorandum identified various processes first used at the San Manuel Mine that resulted in significant productivity gains and cost reductions. Included in the memo was the formation of high-performance teams. The teams, encouraged to suggest and implement more efficient production techniques, operated with greater autonomy and less supervision than previously. Magma planned to introduce these processes throughout its underground operations.

Idaho.—In early April, ASARCO Incorporated, operator and 50% holder of the Coeur Mine, temporarily ceased operations at the mine. Company officials, citing low silver prices for the decision, placed the mine on a care-and-

maintenance basis. Reportedly, exploration to locate new ore reserves was to continue. On December 31, Coeur d'Alene Mines Corp. acquired Callahan Mining Corp. With the acquisition, Coeur's interest in the Coeur Mine increased from 45% to 50%. In 1991, Asarco milled about 34,000 tons of ore and recovered 12 tons of silver at the Coeur Mine. The previous year's production was 16 tons of silver.⁵

At its DeLamar Mine, NERCO Minerals Co. began a two-phase program to detoxify the mine's tailings pond. The company undertook the program, at least in part, in response to a bird mortality problem at the mine. The company planned to lower the cyanide concentration of the pond by injecting it with hydrogen peroxide which would destroy the residual cyanide. Additionally, the company planned to construct a cyanide recovery facility to remove the cyanide from the tailings before their deposition in the pond. The DeLamar Mine produced 1 ton of gold and 53 tons of silver during the year.⁶

With its acquisition of Callahan Mining, Coeur d'Alene Mines obtained a 50% nonoperating interest in the Galena Mine. Asarco, the mine's operator, milled about 166,000 tons of ore during 1991 and recovered 102 tons of silver.⁷

Near the end of June, Hecla Mining Co. acquired CoCa Mines Inc. CoCa's major asset was the Grouse Creek project, a gold-silver deposit in southern Idaho. With the acquisition of Grouse Creek, Hecla increased its reserves significantly. Hecla announced plans to proceed with development of the project, and production could begin by late 1993. At yearend 1991, reserves at the Grouse Creek project were 13,600,000 tons grading 1.5 grams per ton gold and 37.3 grams per ton silver.⁸

Cost reductions continued to benefit the Lucky Friday Mine. Despite operating at a loss, production continued throughout the year. Hecla, which owns and operates the mine, cited the continuing productivity improvements in the decision to keep the mine open. Corporate officials stated that because of the improvements the mine was now

among the lowest cost domestic primary silver producers. According to the literature, the reduced operating costs have made it less costly to keep the mine operating than to place it on care and maintenance. For the year, the Lucky Friday Mine produced 58 tons of silver from 138,000 tons of ore.⁹

MinVen Gold Corp. acquired the 50% interest held by its joint-venture partner in the Stibnite Mine. MinVen took over operation of the mine in April. Production at the heap-leach operation reportedly improved following the resumption of crushing the ore before leaching.

In early June, Sunshine Precious Metals Inc. reduced the operating rate at the Sunshine Mine from 162 tons per year to about 81 tons per year as a consequence of the low silver price and the need to preserve cash. The new operating plan reportedly was less expensive than either full operation or placing the mine on care and maintenance. Company officials stated that the new plan would allow the mine to respond quickly to rising prices. In early July, the company negotiated new labor agreements covering most of the unionized workers at the Sunshine Mine. The new agreements cover a 3-year period, and were not expected to result in any significant increase in labor costs. Sunshine Precious Metals was a wholly owned subsidiary of the Sunshine Mining Co., whose major asset was the Sunshine Mine, mill, and refinery. During 1991, the Sunshine Mine produced 115 tons of silver.¹⁰

During the year, Hecla Mining Co. mined the remaining oxide ore at the Yellow Pine Mine. The heap-leach operation produced 255 kilograms of silver in 1991.¹¹ The Yellow Pine Mine won the State of Idaho's "Excellence in Operation Award" for its environmental work. Corporate officials expected leaching at the site to be completed in 1992.

Montana.—Unseasonably heavy precipitation hindered operations at the Beal Mountain Mine during the first half of 1991. The rains inhibited crusher

operation and diluted the mine's leach solutions, thereby reducing gold and silver production. Increased production during the second half made up most of the first half production shortfall. To guard against a recurrence, Pegasus Gold Inc. doubled the mine's solution treatment capacity by installing five new carbon columns in the plant. During 1991, Beal Mountain recovered 1,472 kilograms of gold and 243 kilograms of silver.¹²

Canyon Resources Corp. mined approximately 1,362,000 tons of ore at its Kendall Mine. The Kendall Mine, an open pit, heap-leach operation produced about 2 tons of gold and 333 kilograms of silver.¹³

Near mid-June, Pegasus took over mining at its Montana Tunnels Mine. Prior to that time, a contractor mined the deposit and Pegasus ran the processing plant. By performing the mining itself, Pegasus expected to realize a significant reduction in its operating costs. During the year, Montana Tunnels mined 3,875,000 tons of ore and recovered 2 tons of gold and 36 tons of silver.¹⁴

As with its Montana Tunnels Mine, Pegasus also took over the mining operations at its Zortman-Landusky Mine. The transition to in-house mining began in October. For 1991, the Zortman-Landusky Mine recovered 4 tons of gold and 30 tons of silver.¹⁵

Nevada.—At its Battle Mountain Complex, Battle Mountain Gold Co. recovered approximately 8 tons of gold and 13 tons of silver from the Fortitude, Labrador, and Surprise deposits.¹⁶ The 1991 output of gold and silver was slightly lower than that for the previous year and probably was attributable to lower ore grades. The company processed more than 1 million tons of ore through its on-site carbon-in-pulp mill and leached an additional 660,000 tons. The Fortitude deposit probably will be depleted in early 1993, but Battle Mountain expects to develop other small, nearby deposits.

Cominco American Inc. halted mining at the Buckhorn Mine in May and crushing operations in June owing to ore depletion. Leaching was believed likely

to continue into 1992. The company began site reclamation during the year and expected to complete its reclamation work in 1992.

In June, workers at the Bullfrog Mine began driving a drift into the North Zone reserves. The mine expected to begin underground production in 1992 using a drift-and-fill mining method. In 1991, the open pit mine produced 6 tons of silver.¹⁷

Although mining ceased at the Candelaria Mine in November 1990, continued leaching resulted in the production of almost 53 tons of silver and 93 kilograms of gold.¹⁸ NERCO Minerals Co., operator of the Candelaria Mine, was proceeding with development of smaller gold deposits near the mine site.

Silver production at the McCoy-Cove Mine increased significantly. The mine consisted of two deposits, with production from two pits and two underground operations. In 1991, the mine produced 175 tons of silver, compared with 62 tons during the previous year.¹⁹ Gold production also increased slightly. Company reports attributed the increases to several developments. One was a new effluent treatment plant completed in 1990. During that year, the company had been forced to reduce the concentration of chemicals used in the mill to help neutralize the mill effluent. With completion of the effluent treatment plant, the mill resumed the use of concentrated chemicals, and gold and silver recovery improved. Another factor for the significant jump in silver production was the increased mining of the Cove deposit. The Cove deposit contained significant quantities of silver, while the McCoy deposit contained only minor amounts. Also cited were increases in the underground mining rates and reduced waterflows in the Cove pit owing to the pit dewatering program. In early 1991, mining depleted the known ore reserves in the bottom of the McCoy pit. Exploration subsequently discovered some additional reserves. These additional reserves probably will be exploited following completion of underground mining in the deposit.

At the Paradise Peak Mine, silver production declined significantly. Gold production was about 6 tons and silver production about 72 tons.²⁰ In 1990, the mine produced 6 tons of gold and 170 tons of silver. Declining ore grades and the depletion of the high silver portion of the Paradise Peak deposit during 1990 were the primary factors in the lower production. To help offset the effects of the declining grades, FMC Gold Co. increased mill throughput at the mine and expanded its heap-leaching activities. The company milled approximately 1.4 million tons of ore and added about 2.9 million tons to the leach pads. The previous year, the company had milled 1.3 million tons and leached about 700,000 tons. During the second half, the company began mining operations at the County Line deposit. Previously, production had been from the original Paradise Peak and Ketchup Flat deposits. FMC began a gain-sharing program aimed at reducing operating costs. Savings from the program were expected to be about \$1.3 million per year.

The Rawhide Mine completed its first full year of operation. The mine, owned and operated by Kennecott Corp., a wholly owned subsidiary of The RTZ Corp. PLC, produced gold and silver.

Magma Copper expanded its property holdings near the Robinson Mine. Among the properties acquired was the Taylor Mine, a former gold-silver producer. NERCO Minerals Co., which owned the Taylor Mine, exchanged its interest in the property for a net smelter royalty on the Robinson copper-gold property. Although the Taylor Mine had been inactive since 1984, the mine's mill had operated since then. Company officials expected the mine to produce copper, gold, and silver. Permitting and various studies were underway at yearend. In 1991, mining near-surface deposits on the Robinson property reportedly resulted in the production of 645 kilograms of gold.²¹

Gold and silver production at the Rochester Mine increased in 1991. Mining operations produced about 6.3 million tons of ore, and silver recovery at the heap-leach operation rose from 149 tons to 178 tons.²² Gold production

increased slightly. Company officials attributed the increased production to the adoption of a new extraction technique called "counter-current leaching." This technique consisted of using the same batch solution to leach the ore on more than one leach pad. After passing through several heaps before processing the pregnant solution contained additional gold and silver. Reportedly, counter-current leaching reduces the volume of solution that must be processed by increasing the concentration of gold and silver in the pregnant solution.

Production at the Sleeper Mine declined, owing in part to a decline in ore grades. To help offset the lower ore grades, Amax Gold Inc. added a larger grinding mill to the operation, thereby increasing its mill capacity to about 2,000 tons per day. The increased capacity will allow the company to mill some lower grade ore previously heap leached, resulting in improved recoveries. For the year, the Sleeper Mine milled 565,000 tons of ore and added 7.5 million tons of ore to its leaching pads. Production at the mine included 9 tons of silver and 6 tons of gold.²³

At the Wind Mountain Mine, Amax Gold Inc. mined about 13 million tons of ore. The heap-leach operation produced 13 tons of silver and 3 tons of gold.²⁴ Mining ceased at the open pit mine near the end of January 1992 owing to the depletion of ore reserves. Reclamation of the site began after that, although leaching continued.

Other States.—Mining resumed in the Cripple Creek mining district in Colorado. Pikes Peak Mining Co. began mining in the Globe Hill area of the district in June. Pikes Peak was a wholly owned subsidiary of NERCO Minerals. With the resumption of mining by Pikes Peak, NERCO Minerals reopened its Victor Mine. The Victor Mine, also in the Cripple Creek district, last produced in January 1986.

Production began at the San Luis Mine in July. The mine, near the town of San Luis, CO, was a typical open pit operation. The mine used a carbon-in-pulp leach circuit to process

approximately 674,000 tons of ore. Although experiencing some startup problems, the mine produced 684 kilograms of gold and 435 kilograms of silver.²⁵

Prior to its acquisition by Coeur d'Alene Mines Corp., Callahan Mining decided to abandon its Ropes Mine, near Ishpeming, MI. The Ropes Mine was an underground operation that produced gold and silver and had a history of ground control problems. Ground control problems near the mine's main shaft, along with low gold and silver prices, resulted in its closure in late September 1989. The mine never reopened. Company officials cited the continually escalating costs of reopening the mine and the continuing low gold prices when announcing their decision.

The Magmont Mine in Missouri reduced its work force by 20% to 151 employees during the year. Company officials cited lower metal prices and the need to remain competitive for the decision. Despite the reduced work force, the mine maintained its production levels and milled more than 1 million tons of ore.

At its copper refinery in El Paso, TX, Phelps Dodge Corp. recovered 60 tons of byproduct silver.²⁶ Feed material for the El Paso refinery came from its copper mines and smelters in Arizona and New Mexico and the Santa Gertrudis Mine, in Mexico. At the Morenci Mine in Arizona, Phelps Dodge mined about 40.4 million tons of ore. At its Chino and Tyrone Mines in New Mexico, the company mined about 16.4 million and 14.3 million tons of ore, respectively.

In Utah, gold and silver production at the Bingham Canyon Mine increased owing in part to an increase in mill throughput and to higher ore grades. The ore mined at Bingham Canyon reportedly contained about 112 tons of silver.²⁷

Consumption and Uses

Apparent U.S. demand for silver in 1991, calculated as refinery production from primary materials and from old scrap plus net imports of refined bullion, was 3,846 tons. Included in the apparent

demand calculation was the amount of silver absorbed by investors and the amount of silver required by the domestic fabricating industry. For the second consecutive year, apparent demand decreased, reflecting the continued lack of investor demand and the effects of the domestic recession.

Near mid-1992, the Silver Institute published estimates of silver consumption in 1991 by end use.²⁸ CPM Group, private consultants, developed the estimates for the Silver Institute. These estimates are reproduced in table 9. According to CPM, domestic silver consumption in 1991 declined from that of the previous year. Probably a major reason for the lower consumption was the economic recession.

Stocks

Total accountable stocks at yearend 1991 had increased by about 79 tons over those of yearend 1990. Continued buildup of stocks held by futures exchanges combined with an increase in industry-held stocks more than compensated for decline in Government-held stocks. Analysts cited the slowdown in the domestic economy and the lack of investor demand as the primary reasons for the continued stock buildup.

The total quantity of Government-held silver continued to decline. The U.S. Mint, as authorized by Congress, used NDS silver for various coinage programs. (See the "Legislation and Government Programs" section of this report.) Since 1985, Government-held stocks have declined by more than 1,600 tons. Various Government coinage programs have consumed nearly all the silver represented by the decrease.

Markets and Prices

The domestic silver price, as quoted by Handy & Harman, declined for the fourth consecutive year despite the lower domestic mine production and the lower quantity of silver recovered from old scrap. Analysts attributed the continued weak price primarily to lower industrial demand, combined with lack of investor

demand. The price began the year at \$4.13 per troy ounce and generally trended downward until the end of February. The low for the year of \$3.58 on February 26 was the lowest daily price since January 1974. Following the end of the Iraq-Kuwait conflict, the price rallied until it reached the high for the year, \$4.53, near mid-June. Although the price subsequently declined, it remained near \$4.00 per troy ounce for the remainder of the year. The London spot price followed a pattern similar to that of the Handy & Harman price. The U.S. dollar equivalent of the London spot price, as quoted in Metals Week, began 1991 at \$4.16 per troy ounce and ended the year at \$3.86. The low and high prices of \$3.54 and \$4.57 occurred on February 25 and June 10, respectively. The average for 1991 was \$4.05.

The amount of silver represented by the future contracts traded on the Commodity Exchange Inc. (COMEX) increased in 1991 to 646,129 tons from 608,634 tons in 1990. At the Chicago Board of Trade, the quantity of silver corresponding to the futures trading volume decreased to 3,654 tons in 1991 from 5,912 tons in 1990. On the Mid-America Commodity Exchange, silver futures trading volume increase to 408 tons in 1991 from 342 tons in 1990.

Foreign Trade

U.S. silver exports decreased in 1991 for the first time in 7 years. The lower domestic mine production and the economic recession, both domestically and in other industrialized countries, may have been contributing factors to the lower exports. The countries with the largest increases in quantities of silver imported from the United States were the United Kingdom and the United Arab Emirates. Shipments to these countries increased about 148 tons and 108 tons, respectively. Increased shipments of refined bullion accounted for the increased trade with both countries. The largest drop in U.S. silver exports were those to Japan, which decreased by 432 tons from those of the previous year. Cumulatively over the past 10 years, the

United States has exported about 10,748 tons of silver. Japan (2,467 tons), Canada (2,397 tons), the United Kingdom (2,166 tons), and France (1,189 tons) have received most of the U.S. silver exports.

Although U.S. silver imports increased in 1991 for the fourth consecutive year, shipments from Canada and Mexico continued to decline. Canadian and Mexican exports to the United States fell by 230 tons and 205 tons, respectively, primarily the result of lower shipments of refined bullion. During the past 10 years, Canada has supplied 11,271 tons and Mexico 12,617 tons of the total U.S. imports of 38,166 tons during that period. The increased imports were due to increased exports by the United Kingdom (453 tons), Peru (204 tons), the Federal Republic of Germany (182 tons), Chile (169 tons), and Malaysia (152 tons).

World Review

The data in table 13 were rated production capacity in mines as of December 31, 1991. Rated capacity was defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable, long-term operating rate, based on the physical equipment of the plant and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

As with U.S. consumption, the Silver Institute publication World Silver Survey 1992 contained estimates of world silver consumption. These estimates are reproduced in table 16.

Australia.—Completion of a project to push back the pit walls reduced the stripping ratio at the Pajingo Mine and provided access to deeper reserves. The mine milled 171,000 tons of ore and produced 2 tons of gold and 4 tons of silver.²⁹ Company officials stated that at current mining rates, the mine's known

reserves would be depleted in 1992. The mill, however, would continue to process stockpiled ore through 1994. Battle Mountain let a contract to ACM Gold Ltd. for future exploration work near the Pajingo Mine.

Aberfoyle Ltd. closed the Que River Mine near yearend owing to exhaustion of the mine's reserves. The zinc-lead-silver operation mined almost 100,000 tons of ore containing an average 156 grams of silver per ton.³⁰

Near mid-March, Niugini Mining Ltd. completed the purchase of the Red Dome Mine in Queensland. The open pit operation used heap leaching, flotation, and carbon-in-leach to recover gold, silver, and copper. In 1991, the mine produced about 1 ton of gold and 4 tons of silver.³¹

Bolivia.—In May, Battle Mountain increased its interest in Empresa Minera Inti Raymi S.A. to 85% from 51%. Battle Mountain acquired 24.5% of Inti Raymi's stock through the acquisition of Westworld Resources Inc. The company obtained the remainder of its share from Zeland Mines S.A. Inti Raymi operated the Kori Kollo heap-leach operation in Bolivia. The company began construction of a new carbon-in-pulp cyanide leach mill, which will be used to treat the sulfide portion of the deposit. In 1991, Kori Kollo recovered 2 tons of gold and 10 tons of silver.³²

Canada.—MinVen Gold Corp. closed the Blackdome Mine following the exhaustion of known ore reserves in mid-January. The company reportedly sold some equipment at the mine and used the proceeds to help carry out reclamation of the site.

Completion of various projects during 1990 and 1991 increased the mill capacity of the Con Mine to 1,000 tons per day from about 700 tons per day. Nerco began installation of an autoclave during the year. The autoclave will be used to treat and stabilize arsenic sludge produced by the mine's former owners as a byproduct of their gold operations. Officials expected the autoclave to

recover some gold from the sludge and be operational by yearend 1992. The mine received an environmental award during the year for this cleanup effort.

Placer Dome Inc. reported the production of 175 tons of silver at the Equity Silver Mine in British Columbia.³³ In 1990, the mine had recovered 229 tons of silver. Company reports attributed the decline in production to the mining and processing of lower grade ores. Future silver production will continue to decline as the mine reaches the end of its planned life.

At its Kidd Creek Div., Falconbridge Ltd. reported the production of 168 tons of silver during 1991.³⁴ The byproduct silver production declined from that of the previous year owing in part to low zinc prices, which caused zinc production to decline. The company reduced both the number of employees in the division and the amount of contract labor used for capital projects as steps toward becoming a lower cost, more competitive operation.

Brunswick Mining and Smelting Corp. Ltd. settled a 10-month strike at its No. 12 Mine in early May. Through the strike, the company reportedly maintained operations at 25% of the normal levels with staff employees. During the year, the mine produced 127 tons of silver by milling 2,531,000 tons of ore.³⁵ Brunswick's smelter produced almost 51.3 tons of silver doré.

Kerr Addison Mines Ltd. closed its Opemiska Mine in June following exhaustion of its remaining reserves. For the year, the mine produced 4 tons of silver.³⁶ The silver production at Kerr's other operations was 9 tons from its Lac Dufault Div., 114 tons from its Samatsum Div., and 6 tons from its Winston Lake Div.

At the Sullivan Mine, Cominco Ltd. milled 1,688,300 tons of ore grading 39 grams of silver per ton, compared with 399,600 tons grading 28 grams of silver per ton the year before.³⁷ The company attributed the higher production primarily to essentially full year continuous operations at the mine. During 1990, low zinc prices and high operating costs had resulted in the mine's closure from January to November. Also cited was the

new labor agreement negotiated the previous year.

Highland Valley Copper Co. negotiated a new 2-year agreement with workers at its Valley Mine. The new agreement provided for wage and benefit improvements. During the year, the mine produced about 33 tons of silver contained in concentrate, compared with about 31 tons the previous year.³⁸

Chile.—Production at the El Indio Complex declined, owing in part to a 26-day strike and the mining of lower grade ore. The El Indio Complex consisted of the El Indio and Tambo Mines. During the year, the operation milled about 982,000 tons of ore and leached 646,000 tons to recover 43 tons of silver.³⁹

At the La Coipa Mine, a new processing plant began operating in October. The new plant had a capacity of 15,000 tons per day and could result in the mine producing more than 6 tons of gold and 500 tons of silver in 1992. The new plant, a conventional cyanide leaching gold and silver recovery plant, replaced an existing 1,000-ton-per-day mill. In 1991, La Coipa recovered 159 tons of silver.

Production began at the San Cristobal Mine in July. The mine was a typical open pit operation using heap leaching to recover gold and silver. Production during the year was lower than expected, owing in part to startup problems. Employees had corrected most of startup problems by yearend. For the year, the mine produced 653 kilograms of gold and almost 2 tons of silver.⁴⁰

Mexico.—Silver production at the Real de Angeles Mine declined in 1991 to 263 tons of silver in response to lower ore grades and lower recoveries.⁴¹ In response to low prices, Placer modified the mine's long-term mining plan to extract the highest grades available and postponed stripping activity.

Near midyear, operations commenced at the Santa Gertrudis Mine, a 2,000-ton-per-day heap-leach operation. Phelps Dodge had a 49% interest in the mine,

with the remainder shared by a group of Mexican investors.

New Zealand.—The Golden Cross Mine began operations during the year. The initial doré pour occurred in December, and commercial production commenced in February 1992. Cyprus Minerals Co. has an 80% interest in the gold-silver operation.

Amax Gold increased its interest in the Waihi Mine from 28.35% to 33.53%. During the year, the open pit gold-silver mine milled 872,000 tons of ore, recovering 2 tons of gold and 11 tons of silver.⁴²

Papua New Guinea.—Production at the Misima Mine increased despite the mining of lower grade material at the original deposit. The company was able to increase the average ore grade processed by blending the lower grade ore with higher grade material from the recently discovered Quartz Mountain zone. Increased mill throughput was an additional factor in the increased production. In 1991, the Misima Mine produced 80 tons of silver.⁴³

At the Porgera Mine, workers completed construction of a pressure oxidation circuit in the third quarter. Production at the mine increased owing to higher mill throughputs and higher recoveries. Future production was believed likely to increase as the pressure oxidation circuit began treating stored tailings.

OUTLOOK

The dominant component of domestic silver supply is silver recovered as a byproduct of the processing of other nonferrous metals such as copper, gold, lead, and zinc. Most nonferrous ores contain some silver. Processing the ores concentrates the silver either in a waste stream or with the principal product. Once concentrated, the additional cost to recover the silver is minimal.

Therefore, the quantity of silver supplied to the market is somewhat independent of the silver price. It is

likely that during the period 1992-94, domestic silver mine production will remain about 2,000 tons per year. Worldwide, mine production of silver should remain about 15,000 tons per year.

Future industrial demand for silver is harder to forecast owing to its many diverse uses. Over the next few years, the industrial demand for silver will likely follow the general economy, either upwards or downwards, but remain about 3,700 tons. Worldwide, silver demand will grow slightly with the gradual opening of new markets in lesser developed countries.

¹Heyl, A. V., W. E. Hall, A. E. Weissenborn, H. K. Stager, W. P. Puffert, and B. L. Reed. Silver. Ch. in the United States Mineral Resources, ed. by D. A. Brobst and W. P. Pratt. U.S. Geol. Survey Prof. Paper 820; 1973; p. 596.

²Hecla Mining Co. 1991 Annual Report, 66 pp.

³Cominco Ltd. 1991 Annual Report, 64 pp.

⁴Magma Copper Co. 1991 10K Report, 69 pp.

⁵Coeur d'Alene Mines Corp. 1991 10K Report, 53 pp.

⁶NERCO Inc. 1991 10K Report, 38 pp.

⁷Work cited in footnote 5.

⁸Work cited in footnote 2.

⁹Work cited in footnote 2.

¹⁰Sunshine Mining Co. 1991 Annual Report, 20 pp.

¹¹Work cited in footnote 2.

¹²Pegasus Gold Inc. 1991 Annual Report, 48 pp.

¹³Canyon Resources Corp. 1991 Annual Report, 36 pp.

¹⁴Work cited in footnote 12.

¹⁵Work cited in footnote 12.

¹⁶Battle Mountain Gold Co. 1991 Annual Report, 56 pp.

¹⁷LAC Minerals Ltd. 1991 Annual Report, 70 pp.

¹⁸Work cited in footnote 6.

¹⁹Echo Bay Mine Ltd. 1991 10K Report, 115 pp.

²⁰FMC Gold Co. 1991 Annual Report, 30 pp.

²¹Work cited in footnote 4.

²²Work cited in footnote 5.

²³Amax Gold Inc. 1991 10K Report, 80 pp.

²⁴Work cited in footnote 23.

²⁵Work cited in footnote 16.

²⁶Phelps Dodge Corp. 1991 10K Report, 70 pp.

²⁷The RTZ Corp. PLC 1991 Annual Report, 66 pp.

²⁸The Silver Institute. World Silver Survey 1992, 113 pp.

Available from the Silver Institute, 1112 Sixteenth St., NW, Suite 2401, Washington, DC 20036.

²⁹Battle Mountain Gold Co. 1991 10K Report, 85 pp.

³⁰Work cited in footnote 3.

³¹Work cited in footnote 29.

³²Work cited in footnote 16.

³³Placer Dome Inc. 1991 Annual Report, 60 pp.

³⁴Noranda Inc. 1991 Annual Report, 57 pp.

³⁵Brunswick Mining and Smelting Corp. Ltd. 1991 Annual Report, 28 pp.

³⁶Kerr Addison Mines Ltd. 1991 Annual Report, 24 pp.

³⁷Work cited in footnote 3.

³⁸Work cited in footnote 3.

³⁹Work cited in footnote 17.

⁴⁰Work cited in footnote 29.

⁴¹Work cited in footnote 33.

⁴²Amax Gold Inc. 1991 Annual Report, 48 pp.

⁴³Work cited in footnote 33.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Silver. Ch. in Mineral Commodity Summaries, annual.

Mineral Industry Surveys, Gold and Silver, monthly.

Minerals Today, bimonthly.

Other Publications

American Metal Market, New York.

Engineering and Mining Journal, Chicago, IL.

Jewelers' Circular-Keystone, Radnor, PA.

Metals Week, New York.

Mining Journal, London.

The Northern Miner, Toronto, Canada.

The Silver Institute Letter, pub. bimonthly by the Silver Institute, Washington, DC.

The Silver Market, compiled by Handy & Harman, New York.

TABLE 1
SALIENT SILVER STATISTICS

		1987	1988	1989	1990	1991
United States:						
Mine production	metric tons	1,241	1,661	2,007	'2,125	1,848
Value	thousands	\$277,063	\$349,339	\$354,971	'\$329,329	\$240,041
Refinery production:						
Domestic and foreign ores and concentrates	metric tons	1,415	1,474	1,718	'1,598	1,879
Secondary (old scrap)	do.	810	852	'714	'454	229
Exports:						
Refined	do.	350	444	430	736	787
Other	do.	493	555	850	1,112	894
Imports for consumption:						
Refined	do.	2,114	2,260	3,062	2,698	2,525
Other	do.	431	497	241	646	1,626
Stocks, Dec. 31:						
Industry	do.	471	480	544	'583	618
Futures exchanges	do.	5,279	5,862	7,795	8,636	8,755
Apparent demand, refined ¹	do.	3,989	4,142	'5,063	'4,014	3,846
Coinage	do.	469	275	'264	265	285
Price, average per troy ounce ²		\$7.01	\$6.54	\$5.50	\$4.82	\$4.04
Employment ³		1,800	2,300	2,800	2,600	1,900
World:						
Mine production	metric tons	'14,019	'14,517	'15,057	'15,122	14,723
Consumption:⁴						
Industry and the arts	do.	15,443	16,671	'16,899	17,409	17,465
Coinage	do.	933	799	'1,141	799	840

¹Revised.
¹Defined as refinery production from primary materials plus refinery production from old scrap plus imports of bullion minus exports of bullion. Represents not only the quantity of silver required by the domestic fabricating industry, some of which may be placed in stocks, but also the quantity of silver demanded by U.S. investors.

²Metals Week Annual Handy & Harman quotation.

³Mine Safety and Health Administration.

⁴Silver Market 1991. Compiled by Handy & Harman.

TABLE 2
MINE PRODUCTION OF RECOVERABLE SILVER IN THE UNITED STATES, BY STATE

(Metric tons)

State	1987	1988	1989	1990	1991
Alaska	(¹)	1	W	W	W
Arizona	114	152	171	173	148
California	4	15	21	21	W
Colorado	27	27	W	23	20
Idaho	W	340	439	¹ 442	337
Missouri	37	45	53	¹ 42	35
Montana	185	192	194	220	222
Nevada	379	608	625	¹ 646	578
New Mexico	58	93	78	48	W
Oregon	W	W	W	W	—
South Dakota	W	3	4	¹ 10	7
Utah	W	W	185	147	W
Other States ²	436	185	239	354	484
Total³	1,241	1,661	2,007	¹2,125	1,848

¹Revised. W Withheld to avoid disclosing company proprietary data; included in "Other States."

²Less than 1/2 unit.

³Includes Illinois, Kentucky, Michigan, New York, South Carolina, Tennessee, Washington, and States indicated by symbol "W."

⁴Data may not add to totals shown because of independent rounding.

TABLE 3
MINE PRODUCTION OF RECOVERABLE SILVER IN THE UNITED STATES, BY MONTH

(Metric tons)

Month	1987	1988	1989	1990	1991
January	99	116	143	¹ 195	137
February	97	114	139	¹ 169	134
March	105	131	166	¹ 184	166
April	103	126	160	¹ 174	164
May	99	129	176	¹ 179	158
June	101	142	174	¹ 180	145
July	110	142	175	¹ 179	150
August	107	152	185	¹ 184	160
September	109	152	179	¹ 164	173
October	105	157	168	¹ 175	159
November	100	150	170	¹ 175	141
December	106	150	173	¹ 164	158
Total¹	1,241	1,661	2,007	¹2,125	1,848

¹Revised.

²Data may not add to totals shown because of independent rounding.

TABLE 4
TWENTY-FIVE LEADING SILVER-PRODUCING MINES IN THE UNITED STATES IN 1991, IN ORDER OF OUTPUT

Rank	Mine	County and State	Operator	Source of silver
1	Greens Creek	Admiralty Island, AK	Greens Creek Mining Co.	Zinc ore.
2	Rochester	Pershing, NV	Coeur Rochester Inc.	Silver ore.
3	McCoy and Cove	Lander, NV	Echo Bay Mining Co.	Gold ore.
4	Troy	Lincoln, MT	ASARCO Incorporated	Copper ore.
5	Bingham Canyon	Salt Lake, UT	Kennecott-Utah Copper Co.	Do.
6	Sunshine	Shoshone, ID	Sunshine Mining Co.	Silver ore
7	Galena	Do.	ASARCO Incorporated	Do.
8	Paradise Peak	Nye, NV	FMC Gold Co.	Gold ore.
9	Lucky Friday	Shoshone, ID	Hecla Mining Co.	Lead-zinc ore.
10	DeLamar	Owyhee, ID	NERCO DeLamar Co.	Gold ore.
11	Candelaria	Mineral, NV	NERCO Metals Inc.	Silver ore.
12	Red Dog	NW Arctic, AK	Cominco Alaska Inc.	Zinc ore.
13	Montana Tunnels	Jefferson, MT	Montana Tunnels Mining Inc.	Do.
14	Mission Complex ¹	Pima, AZ	ASARCO Incorporated	Copper ore.
15	White Pine	Ontonagon, MI	Copper Range Co.	Do.
16	Zortman-Landusky	Phillips, MT	Pegasus Gold Inc.	Gold ore.
17	Bagdad	Yavapai, AZ	Cyprus Bagdad Copper Co.	Copper ore.
18	Tyrone	Grant, NM	Phelps Dodge Corp.	Do.
19	Wind Mountain	Washoe, NV	Amex Gold Corp.	Gold ore.
20	Continental	Silver Bow, MT	Montana Resources Inc.	Copper ore.
21	Morenci	Greenlee, AZ	Phelps Dodge Corp.	Do.
22	Ray Unit	Pinal, AZ	ASARCO Incorporated	Do.
23	Denton-Rawhide	Mineral, NV	Kennecott Rawhide Mining Co.	Gold ore.
24	San Manuel	Pinal, AZ	Magma Copper Co.	Copper ore.
25	Coeur	Shoshone, ID	ASARCO Incorporated	Silver ore.

¹Includes Eisenhower, Mission, Pima, and San Xavier Mines.

TABLE 5
SILVER PRODUCED IN THE UNITED STATES, BY STATE, TYPE OF MINE, AND CLASS OF ORE

Year and State	Placer (metric tons of silver)	Lode			
		Gold ore		Silver ore	
		Metric tons	Metric tons of silver	Metric tons	Metric tons of silver
1987	1	62,044,114	221	7,944,696	432
1988	(1)	108,310,781	372	9,573,505	674
1989	W	155,188,564	528	4,450,703	524
1990	W	186,690,461	627	W	W
1991:					
Alaska	W	—	—	—	—
Arizona	—	1,360,973	W	—	—
California	(1)	17,918,664	15	—	—
Colorado	—	2,012,764	W	—	—
Idaho	—	1,132,792	W	W	W
Michigan	—	—	—	—	—
Missouri	—	—	—	—	—
Montana	—	W	W	—	—
Nevada	W	105,803,397	343	W	W
New Mexico	—	W	W	—	—
New York	—	—	—	—	—
South Carolina	—	W	W	—	—
South Dakota	W	5,727,349	7	—	—
Tennessee	—	—	—	—	—
Utah	—	4,639,301	15	—	—
Washington	—	W	W	—	—
Total	W	159,990,749	498	W	W
Percent of total silver	W	XX	27	XX	W

	Lode				Total ⁴	
	Copper ore		Other ^{2 3}		Metric tons	Metric tons of silver
	Metric tons	Metric tons of silver	Metric tons	Metric tons of silver		
1987	201,434,248	477	W	W	279,780,498	1,241
1988	222,306,768	485	W	W	350,625,607	1,661
1989	230,558,434	529	W	W	407,088,486	2,007
1990	240,620,259	492	W	W	445,497,037	2,125
1991:						
Alaska	—	—	W	W	W	W
Arizona	W	W	W	W	169,227,050	148
California	W	W	—	—	W	W
Colorado	—	—	W	W	W	20
Idaho	—	—	W	W	1,616,531	337
Michigan	W	W	—	—	W	W
Missouri	—	—	6,403,832	35	6,403,832	35
Montana	W	W	W	W	39,215,732	222
Nevada	W	W	W	W	110,014,894	578
New Mexico	W	W	—	—	W	W
New York	—	—	W	W	W	W
South Carolina	—	—	—	—	W	W

See footnotes at end of table.

TABLE 5—CONTINUED
SILVER PRODUCED IN THE UNITED STATES

	Lode				Total ⁴	
	Copper ore		Other ^{2 3}		Metric tons	Metric tons of silver
	Metric tons	Metric tons of silver	Metric tons	Metric tons of silver		
South Dakota	—	—	—	—	5,727,349	7
Tennessee	—	—	W	W	W	W
Utah	W	W	—	—	W	W
Washington	—	—	—	—	W	W
Total	261,389,296	480	W	W	439,660,399	1,848
Percent of total silver	XX	26	XX	W	XX	100

¹Revised. W Withheld to avoid disclosing company proprietary data; included in "Total," where applicable. XX Not applicable.

²Less than 1/2 unit.

³Includes lead, zinc, copper-lead, lead-zinc, copper-zinc, copper-lead-zinc ores, and old tailings, etc.

⁴Includes silver recovered from tungsten and fluor spar ores.

⁵Data may not add to totals shown because of independent rounding.

TABLE 6
SILVER PRODUCED IN THE UNITED STATES BY CYANIDATION¹

Year	Leaching in vats, tanks, and closed containers ^{2 3}		Leaching in open heaps or dumps ⁴	
	Ore treated (metric tons)	Silver recovered (metric tons)	Ore treated (metric tons)	Silver recovered (metric tons)
1987	² 22,900,343	280	⁴ 45,256,274	254
1988	² 26,593,821	302	⁴ 86,870,554	456
1989	² 38,855,007	300	⁴ 119,199,347	490
1990	47,279,850	290	138,974,999	⁴ 498
1991	50,699,169	176	112,808,497	537

¹Revised.

²May include small quantities recovered by leaching with thiourea, by bioextraction, and by proprietary processes.

³Including autoclaves.

⁴May include small quantities recovered by gravity methods.

⁵May include tailings and waste ore dumps.

TABLE 7
LODE SILVER PRODUCED IN THE UNITED STATES, BY STATE

Year and State	Amalgamation		Cyanidation		Smelting of concentrates			Smelting of ore		Total ore processed ^{1 2} (metric tons)	Total silver recovered ² (metric tons)
	Ore treated (metric tons)	Silver recovered (metric tons)	Ore treated (metric tons)	Silver recovered (metric tons)	Ore concentrated (metric tons)	Concentrates smelted (metric tons)	Silver recovered (metric tons)	Ore smelted (metric tons)	Silver recovered (metric tons)		
1987	W	W	68,156,617	534	211,446,971	4,459,843	696	W	W	279,780,498	1,240
1988	1,512	(³)	113,464,375	758	236,925,134	4,943,949	884	239,195	19	350,625,607	1,661
1989	W	W	158,054,354	790	248,846,575	5,164,847	1,195	W	W	407,088,486	2,007
1990	1,230	(³)	186,254,849	788	259,153,747	6,214,949	W	87,210	W	445,497,037	2,125
1991:											
Alaska	—	—	—	—	W	W	W	—	—	W	W
Arizona	—	—	1,350,509	(³)	167,860,487	2,757,629	145	13,866	3	169,227,050	148
California	—	—	17,918,665	15	W	W	W	—	—	17,918,665	W
Colorado	W	W	2,012,764	4	W	W	W	—	—	2,347,744	20
Idaho	—	—	1,132,792	W	483,739	W	279	—	—	1,616,531	337
Michigan	—	—	—	—	W	W	W	—	—	W	W
Missouri	—	—	—	—	6,403,832	531,533	35	—	—	6,403,832	35
Montana	W	W	W	W	22,588,939	251,984	189	—	—	39,215,732	222
Nevada	—	—	109,909,503	575	W	W	W	31,507	1	110,014,894	578
New Mexico	—	—	—	—	W	W	W	W	W	W	W
New York	—	—	—	—	W	W	W	—	—	W	W
South Carolina	—	—	W	W	—	—	—	—	—	W	W
South Dakota	—	—	5,727,349	7	—	—	—	—	—	5,727,349	7
Tennessee	—	—	—	—	W	W	W	—	—	W	W
Utah	—	—	4,602,462	9	W	W	W	W	W	W	W
Washington	—	—	W	W	488,763	24,774	8	—	—	W	W
Total	W	W	163,507,666	713	260,212,391	6,249,955	W	135,336	W	439,660,399	1,848

¹Revised. W Withheld to avoid disclosing company proprietary data; included in "Total," where applicable.

²Includes old tailings and some nonsilver-bearing ores not separable, in amounts ranging from 0.04% to 0.12% of the totals for the years listed. Excludes fluor spar, molybdenum, and tungsten ores from which silver was recovered as a byproduct and excludes ores leached for recovery of copper.

³Data may not add to totals shown because of independent rounding.

⁴Less than 1/2 unit.

TABLE 8
U.S. REFINERY PRODUCTION OF SILVER

(Metric tons)

Raw material	1987	1988	1989	1990	1991
Concentrates and ores:					
Domestic and foreign	1,415	1,474	1,718	1,598	1,879
Old scrap	810	852	714	454	229
New scrap	1,316	1,505	1,495	1,221	1,634
Total¹	3,541	3,832	3,927	3,274	3,743

¹Revised.

¹Data may not add to totals shown because of independent rounding.

TABLE 9
ANNUAL U.S. FABRICATION DEMAND

(Metric tons)

End use	1987	1988	1989	1990	1991
Photography	1,872	1,944	2,028	2,115	2,053
Electrical contacts and conductors	706	715	731	709	569
Batteries	75	78	87	93	96
Sterlingware	118	109	106	109	109
Jewelry	131	90	75	62	62
Silverplate	78	81	84	87	87
Brazing alloys and solders	174	—	—	—	—
Catalysts	75	81	87	93	103
Medallions and commemorative objects	131	—	—	—	—
Dental and medical supplies	40	44	53	56	—
Mirrors	31	34	34	37	34
Bearings	9	—	—	—	—
Miscellaneous ¹	140	389	448	535	579
Total industrial consumption²	3,586	3,484	3,732	3,891	3,692
Coinage	379	246	212	283	280
Grand total²	3,966	3,729	3,944	4,180	3,972

¹Includes end uses marked with dashes.

²Data may not add to totals shown because of independent rounding.

Source: See footnote 28.

TABLE 10
YEAREND STOCKS OF SILVER IN THE UNITED STATES

(Metric tons)

	1987	1988	1989	1990	1991
Industry	471	480	544	583	618
Futures exchanges	5,279	5,862	7,795	8,636	8,755
Department of the Treasury	1,229	1,201	997	840	1,028
Department of Defense	75	81	81	31	23
National Defense Stockpile	3,517	3,310	2,973	2,866	2,611

Revised.

TABLE 11
U.S. SILVER PRICES

(Dollars per troy ounce)

Period	Low		High		Average
	Price	Date	Price	Date	
1987	5.36	Jan. 7	10.20	Apr. 27	7.01
1988	6.01	Nov. 21 and Dec. 29	7.99	July 21	6.54
1989	5.02	Sept. 15	6.17	Jan. 23	5.50
1990	3.93	Dec. 18	5.39	Feb. 7	4.82
1991:					
January	3.79	Jan. 24 and 28	4.23	Jan. 7 and 15	4.02
February	3.58	Feb. 26	3.85	Feb. 4	3.72
March	3.73	Mar. 1	4.16	Mar. 8	3.96
April	3.87	Apr. 29	4.08	Apr. 3	3.97
May	3.95	May 1 and 2	4.15	May 28	4.04
June	4.15	June 5	4.53	June 10 and 11	4.39
July	4.02	July 30	4.49	July 10	4.30
August	3.82	Aug. 30	4.05	Aug. 1	3.94
September	3.87	Sept. 5	4.21	Sept. 24	4.03
October	4.06	Oct. 14 and 28	4.18	Oct. 2	4.10
November	4.01	Nov. 7 and 8	4.12	Nov. 25	4.06
December	3.82	Dec. 12 and 31	4.06	Dec. 6	3.91
Average and date	3.58	Feb. 26	4.53	June 10 and 11	4.04

Source: Metals Week Handy & Harman daily quotation.

TABLE 12
U.S. EXPORTS OF SILVER, BY COUNTRY¹

Year and country	Ores and concentrates		Wastes and scrap		Doré and precipitates		Refined bullion		Total ²	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
1987	472	\$150	425,325	\$96,738	67,286	\$16,294	349,610	\$79,123	842,693	\$192,305
1988	25,450	1,416	475,481	99,797	53,733	10,844	443,831	94,029	998,495	206,086
1989	607	166	770,788	145,340	78,664	15,478	430,110	77,812	1,280,169	238,797
1990	21,861	3,994	1,077,421	159,194	13,184	2,353	735,993	119,892	1,848,458	285,434
1991:										
Austria	—	—	—	—	—	—	873	162	873	162
Belgium	—	—	150,696	21,422	—	—	—	—	150,696	21,422
Brazil	—	—	—	—	—	—	2,028	402	2,028	402
Canada	14	3	338,200	52,586	—	—	22,885	3,975	361,100	56,564
China	—	—	355	53	—	—	—	—	355	53
France	—	—	115,998	15,538	26,620	3,612	686	99	143,304	19,250
Germany, Federal Republic of	—	—	15,165	2,115	2,764	398	10,872	2,156	28,801	4,669
Hong Kong	—	—	3,152	755	—	—	23,481	3,244	26,633	3,998
Ireland	—	—	—	—	—	—	893	88	893	88
Israel	—	—	2,182	320	—	—	—	—	2,182	320
Italy	—	—	1,826	279	—	—	18	3	1,844	282
Japan	—	—	66,092	8,072	22,370	4,235	202,764	30,893	291,226	43,200
Korea, Republic of	27	5	4,687	766	—	—	87,806	14,658	92,519	15,428
Mexico	—	—	613	95	—	—	—	—	613	95
Netherlands	—	—	3,994	748	—	—	—	—	3,994	748
Singapore	—	—	—	—	—	—	49,551	6,672	49,551	6,672
Spain	—	—	15,814	2,200	10	6	41	7	15,866	2,213
Sweden	—	—	21,716	2,909	—	—	—	—	21,716	2,909
Switzerland	—	—	964	233	229	43	242	46	1,435	322
Taiwan	29	5	114	17	668	114	759	133	1,568	269
United Arab Emirates	—	—	—	—	—	—	107,683	14,240	107,683	14,240
United Kingdom	14	10	98,055	15,722	459	74	268,370	37,054	366,898	52,860
Uruguay	—	—	—	—	—	—	8,045	1,306	8,045	1,306
Other	145	26	603	185	6	4	477	87	1,232	302
Total ²	229	49	840,229	124,015	53,128	8,486	787,474	115,224	1,681,058	247,774

¹Because of the implementation of the Harmonized Tariff System in Jan. 1989, export data may not be comparable with previous years' data.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 13
U.S. IMPORTS OF SILVER, BY COUNTRY¹

Year and country	Ores and concentrates		Wastes and scrap		Doré and precipitates		Refined bullion		Total ²	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
1987	83,401	\$18,019	105,881	\$22,514	242,017	\$53,858	2,113,765	\$460,235	2,545,064	\$554,627
1988	191,324	35,508	60,470	12,995	245,122	52,840	2,260,049	476,181	2,756,964	577,524
1989	7,013	2,301	90,753	96,254	142,739	27,943	3,061,548	578,781	3,302,054	705,278
1990	90,202	23,203	507,649	86,421	48,449	8,741	2,697,926	437,380	3,344,229	555,744
1991:										
Australia	—	—	2,234	12	—	—	—	—	2,234	12
Belgium	37	4	73,270	497	—	—	—	—	73,308	501
Brazil	—	—	2,721	15	—	—	22	7	2,743	22
Canada	12,553	2,340	91,170	16,939	16,301	2,528	789,683	102,903	909,708	124,710
Chile	—	—	383	60	15,043	4,494	206,537	33,038	221,962	37,591
Denmark	—	—	45,477	120	—	—	—	—	45,477	120
Dominican Republic	—	—	20,573	625	23,919	3,593	33	6	44,525	4,224
Germany, Federal Republic of	115	15	244,452	3,631	—	—	10,026	1,248	254,593	4,893
Malaysia	—	—	156,878	2,788	—	—	19,664	2,908	176,542	5,697
Mexico	8,614	1,283	1,031	2,560	61,914	9,511	1,071,439	142,346	1,142,998	155,699
Peru	—	—	—	—	30,623	4,887	427,606	56,034	458,228	60,921
Philippines	—	—	109,794	2,453	—	—	—	—	109,794	2,453
Singapore	—	—	9,919	161	—	—	—	—	9,919	161
South Africa, Republic of	—	—	86,594	46,585	—	—	—	—	86,594	46,585
Sweden	—	—	393	14,129	—	—	—	—	393	14,129
Switzerland	4	5	6,494	51,546	—	—	—	—	6,497	51,550
Taiwan	—	—	615	1,942	—	—	—	—	615	1,942
United Kingdom	—	—	599,540	5,613	—	—	—	—	599,540	5,613
Zaire	—	—	—	—	4,035	726	—	—	4,035	726
Other	100	13	963	3,622	1	1	124	24	1,187	3,662
Total ²	21,422	3,659	1,452,501	153,299	151,836	25,740	2,525,133	338,514	4,150,893	521,212

¹Because of the implementation of the Harmonized Tariff System in Jan. 1989, import data may not be comparable with previous years' data.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 14
WORLD ANNUAL SILVER PRODUCTION CAPACITY,¹
DECEMBER 31, 1991

(Metric tons)

	Rated capacity
North America:	
Canada	1,380
Mexico	2,420
United States	2,130
Other	160
Total	6,090
South America:	
Chile	520
Peru	2,050
Other	420
Total	2,990
Europe:	
Poland	1,060
Spain	370
U.S.S.R.	1,500
Other	890
Total	3,820
Africa	750
Asia:	
Japan	360
Other	680
Total	1,040
Oceania:	
Australia	1,120
Other	70
Total	1,190
World total	15,880

¹Includes capacity at operating plants as well as at plants on standby basis.

TABLE 15
SILVER: WORLD MINE PRODUCTION, BY COUNTRY¹

(Kilograms)

Country ²	1987	1988	1989	1990	1991 ³
Algeria*	3,750	3,750	3,000	2,800	2,500
Argentina	59,667	79,415	83,436	82,657	56,359
Australia	1,119,291	1,117,528	1,075,000	1,138,000	1,180,000
Bolivia	141,987	231,766	267,084	310,543	337,061
Brazil ⁴	¹ 110,400	124,061	172,117	223,052	225,000
Bulgaria*	⁸ 0,000	71,000	59,000	54,000	40,000
Burma	26,096	9,207	6,843	5,298	5,387
Canada (shipments)	1,374,992	1,443,166	1,262,163	1,399,572	1,400,000
Chile	499,761	506,501	545,412	654,603	660,000
China*	100,000	110,000	125,000	125,000	150,000
Colombia ⁵	4,977	6,563	6,847	6,591	6,600
Costa Rica*	⁶ 62	⁶ 62	⁶ 194	⁶ 115	⁶ 100
Czechoslovakia*	30,000	30,000	30,000	25,000	20,000
Dominican Republic	35,707	39,595	22,614	21,630	21,955
Ecuador*	⁶ 60	⁶ 60	⁶ 60	⁶ 60	⁶ 60
Fiji	840	995	1,055	⁸ 00	700
Finland	44,198	31,411	31,127	² 8,508	25,000
France	25,194	24,074	² 0,600	² 2,100	20,000
Germany, Federal Republic of: ⁶					
Eastern states	⁶ 0,000	⁶ 0,000	⁵ 9,700	² 0,000	NA
Western states	³ 0,890	² 0,000	⁹ ,000	⁸ ,000	NA
Total	90,890	80,000	68,700	28,000	22,000
Ghana*	510	580	668	840	1,300
Greece*	⁵ 1,881	⁶ 1,000	60,000	62,000	60,000
Greenland	13,001	14,300	14,700	⁹ ,600	—
Honduras	23,234	58,447	49,892	¹ 8,788	20,000
India	37,946	40,958	35,499	³ 3,206	³ 1,758
Indonesia	50,485	61,538	⁷ 2,498	67,315	⁸ 0,294
Iran*	28,000	30,000	41,000	38,000	40,000
Ireland	7,185	5,598	7,247	⁷ ,200	7,000
Italy ^{7 6}	82,031	91,563	96,036	¹ 03,400	¹ 78,400
Japan	281,020	251,971	155,792	149,920	¹ 70,676
Korea, North*	49,800	49,800	50,000	50,000	50,000
Korea, Republic of ⁵	209,058	226,687	239,214	238,236	235,000
Malaysia	15,797	10,775	13,007	12,558	³ 13,440
Mexico	2,414,954	2,358,907	2,306,091	2,346,336	² ,196,100
Morocco	⁴ 3,900	226,216	236,611	² 41,108	² 00,000
Namibia	103,264	116,520	108,247	⁹ 3,000	89,000
New Zealand	—	1,845	4,837	4,914	11,000
Nicaragua	888	776	1,113	1,095	¹ ,543
Papua New Guinea	61,066	70,408	93,672	¹ 30,000	¹ 24,880
Peru	2,054,448	1,551,598	¹ ,840,000	1,724,923	¹ ,769,743
Philippines	52,374	⁵ 4,634	⁵ 0,630	⁴ 7,110	³ 8,414
Poland	830,992	1,062,993	1,003,000	⁸ 32,000	870,000
Portugal	746	877	20,115	⁴ 3,100	43,500
Romania*	20,000	23,000	26,000	¹ 2,000	10,000
Saudi Arabia*	—	3,600	10,800	⁶ 10,800	10,800

See footnotes at end of table.

TABLE 15—CONTINUED
SILVER: WORLD MINE PRODUCTION, BY COUNTRY¹-CONTINUED

(Kilograms)

Country ²	1987	1988	1989	1990	1991 ³
Solomon Islands	—	⁶ 8	⁶ 7	⁶ 5	³ 6 ⁴
South Africa, Republic of	208,118	199,745	¹ 179,829	¹ 181,003	³ 171,554
Spain	350,008	353,034	¹ 530,000	⁵ 500,000	500,000
Sweden	254,107	207,804	227,715	² 242,685	225,000
Taiwan	9,856	8,388	6,491	⁶ 6,000	—
Tunisia ⁴	1,600	1,600	1,600	1,600	1,600
Turkey ⁵	8,800	22,500	28,500	³ 33,300	38,800
U.S.S.R. ⁶	1,510,000	1,520,000	1,520,000	1,400,000	1,300,000
United States	1,241,000	1,661,425	2,007,436	2,125,000	³ 1,848,000
Yugoslavia ³	165,221	138,970	¹ 127,412	¹ 105,327	94,000
Zaire	36,767	74,000	¹ 70,000	¹ 84,000	80,000
Zambia ⁷	27,843	24,093	¹ 19,719	¹ 17,031	17,000
Zimbabwe	25,351	21,953	22,305	² 21,221	21,200
Total	¹ 14,019,123	¹ 14,517,265	¹ 15,057,935	¹ 15,122,950	14,722,728

⁴Estimated. ⁵Revised. NA Not available.

¹Recoverable content of ores and concentrates produced unless otherwise specified. Table includes data available through June 23, 1992.

²In addition to the countries listed, Botswana produces silver (probably 1 kilogram or less per year) and Austria and Thailand may produce silver, but information is inadequate to make reliable estimates of output levels.

³Reported figure.

⁴Of total production, the following quantities, in kilograms, are identified as placer silver (the balance being silver content of other ores and concentrates): 1987—20,000; 1988—34,319 (revised); 1989—58,000 (revised); 1990—52,000 (revised); and 1991—52,000 (estimated).

⁵Smelter and/or refinery production.

⁶Includes production from imported ores.

⁷Year beginning Apr. 1 of that stated.

TABLE 16
SILVER: WORLD FABRICATION DEMAND

(Metric tons)

End use	1987	1988	1989	1990	1991
Photography:					
United States	1,872	1,944	2,028	2,115	2,053
Japan	1,596	1,767	1,704	1,835	1,897
Western Europe	1,636	1,773	1,776	1,835	1,866
Total	5,104	5,484	5,508	5,785	5,816
Jewelry and silverware:					
United States	327	280	264	258	258
Japan	68	93	109	137	124
Western Europe	1,658	1,782	1,984	2,124	2,274
Total¹	2,053	2,155	2,358	2,519	2,656
Electronic and batteries:					
United States	781	793	818	802	665
Japan	218	261	295	314	280
Western Europe	899	980	1,082	1,079	1,082
Total¹	1,900	2,034	2,196	2,196	2,028
Other uses:					
United States	603	467	622	722	715
Japan	986	1,110	1,070	1,098	1,154
Western Europe	551	594	650	644	650
Total¹	2,140	2,171	2,342	2,463	2,519
Other countries	2,196	2,255	2,448	2,970	2,886
Coinage	946	787	818	927	930
Grand total¹	14,339	14,886	15,670	16,861	16,836

¹Data may not add to totals shown because of independent rounding.

Note.—Excludes transitional economies.

Source: See footnote 28.

SLAG—IRON AND STEEL

By Cheryl Cvetic Solomon

Ms. Solomon, a physical scientist with 6 years' U.S. Bureau of Mines experience, has been the commodity specialist for iron and steel slag since 1990. Domestic survey data were prepared by Shirley Miller and Robin Kaiser, mineral data assistants.

Iron and steel slags are byproducts of the iron and steel industry and are used in numerous commercial applications in construction and roadbuilding. Slags are used in road bases, various types of concrete aggregates and products, glass manufacture, mineral wool, railroad ballast, sewage treatment, and soil conditioning.

In 1991, the Federal Environmental Protection Agency (EPA) concluded that regulation of iron and steel slags as a hazardous waste under the Resource Conservation and Recovery Act (RCRA) was inappropriate. This decision presented the final regulatory determination that iron and steel slags were not subject to Federal regulation as hazardous wastes. (See Legislation and Government Programs section of this report.)

Research during the year emphasized the use of granulated slag as an additive to cement. The slag provided the cement with greater durability, strength, and resistance to sulfate attack among other qualities. Other research indicated that slag could be used to immobilize radioactive waste. (See Current Research section of this report.)

Domestic consumption of iron slag showed a moderate decrease when compared with that of 1990, while the consumption of steel slag increased slightly from that of 1990.

Beginning with this Iron and Steel Slag Annual Report, all quantities are given in metric tons. In 1960, an International System of Units was adopted by the 11th General Conference of Weights and Measures. This system is called the MKS system, or metric system, and most

countries of the world have adopted it as their official system of measurement.

Congress enacted the Metric Conversion Act of 1975 on December 23, 1975. The act was amended on August 23, 1988, by the Omnibus Trade Act of 1988, which was to enhance the competitiveness of the Nation's industries and to improve the management of the U.S. trade strategy. The Metric Conversion Act declared that the national policy was to prefer the metric system in U.S. trade and commerce and called for the U.S. Government to convert to the metric system.

On July 25, 1991, the President of the United States signed Executive Order 12770 to implement the congressional designation of the metric system of measurement as the preferred system of weights and measures for U.S. trade and commerce.

The U.S. Bureau of Mines, in an effort to provide statistical data on iron and steel slag in units most consistent with international usage, has converted all numbers in the iron and slag tables to metric tons and will henceforth report iron and steel slag data in metric tons (mt) unless otherwise noted. To convert from metric tons to short tons, the quantity should be multiplied by the conversion factor 1.10231. To convert short tons to metric tons the quantity should be multiplied by the conversion factor 0.907185. To convert from kilometers to miles, the quantity should be multiplied by the conversion factor 0.6215. To convert miles to kilometers the quantity should be multiplied by 1.609.

DOMESTIC DATA COVERAGE

Data for sales, use, and transportation of iron and steel slag are developed by the U.S. Bureau of Mines from a voluntary survey of U.S. processors. Of the 105 operations canvassed, 97 responded and the rest were estimated, representing 100% of the total sales or use quantity data shown in table 1. Value data had to be estimated for several operations using reports from prior years adjusted by industry trends.

BACKGROUND

Definitions, Grades, and Specifications

Slags are produced in many metallurgical operations, but this publication deals exclusively with iron slag and steel slag produced during the ironmaking and steelmaking processes.

In the production of iron, the blast furnace is charged with iron ore, flux stone (limestone and/or dolomite), and coke for fuel. Two products are obtained from the furnace: molten iron and slag. The slag consists primarily of the silica and alumina from the original iron ore combined with calcium and magnesium oxides from the flux stone. It comes from the furnace as a liquid at temperatures of about 2,700° F, resembling molten lava.

The blast furnace operation is a continuous process. The raw materials are fed into the top, and the products, molten iron and liquid slag, are drawn off at regular intervals throughout the entire day. Slag is produced at an average worldwide rate of 250 to 350 kilograms

of slag per ton of hot metal (kg/thm) or pig iron.¹ The slag is usually run into iron ladles for conveyance to the cooling pit, or it may run straight into a cooling pit close to the furnace. When the material cools and solidifies the gases create voids within the structure. These voids impart special engineering properties when the slag is used as an aggregate.²

The density and porosity of the slag are affected by the conditions of cooling as well as by its chemical composition. Depending upon the manner in which the molten slag is cooled and solidified, three distinct types of blast furnace slag can be produced: air-cooled, expanded, and granulated.

Air-cooled slag is allowed to run into a pit adjacent to the furnace or is transported in large ladles and poured into a pit some distance away. Solidification takes place under the prevailing atmospheric conditions, after which cooling may be accelerated by water sprays on the solidified mass. After a pit has been filled and cooled sufficiently to be handled, the slag is dug, crushed, and screened to desired aggregate sizes.

Expanded slag is formed by controlled processing of molten blast furnace slag with water, or with water and other agents such as steam or compressed air, or both. The formation of gases and steam increases the cellular or vesicular nature of the slag, producing a lightweight product. Several methods of expanding the slag are employed involving the pouring of molten slag in open pits or the use of mechanical devices, one of which produces particles in pellet form. Expanded slag is a strong lightweight aggregate suitable for making lightweight concrete, either as building blocks or as structural elements for buildings or for bridge decks, for example.

Granulated slag is produced when molten slag is cooled rapidly by means of high-pressure water jets and solidifies into a glassy, granular product. This is the most rapid cooling process, producing little or no crystallization. The granulated slag may be crushed and

screened or pulverized for various applications.

The steel industry also produces steel slag during the steelmaking process. The manufacture of steel involves the removal from the iron of excess quantities of carbon and silicon by oxidation. Steel slag is composed of roughly 50% lime. The other two main constituents are silica and iron oxide. The steel slag contains significant iron quantities and few voids making it a tough, hard, heavier material. Different types of steel slag are generated from the open-hearth, basic oxygen, and electric arc furnaces.

Air-cooled and expanded slag are defined by ASTM standard C 125-88.³ Granulated slag is specified by ASTM C 989-88, "Standard Specification for Ground Iron Blast Furnace Slag for Use in Concrete and Mortars," which was first published in 1982.⁴

The specifications for steel slag aggregate used in asphaltic concrete are covered by ASTM D 5106-91, "Standard Specification for Steel Aggregates for Bituminous Paving Mixtures."⁵

Industry Structure

In general, most slag processors operate under contracts of 3 to 10 years with steel companies. The services the slag processors typically offer to the steel mill industry are hauling and transport of the slag away from the mill site, processing of the slag, and recovery and distribution of metallics and nonmetallics. Because slag hauling and processing facilities are capital intensive, the slag processors usually try to negotiate a long-term initial contract with the steel company to recover the capital investment. Subsequent contracts may be shorter.

Depending upon the specific situation at the mill site, the slag processor may assume ownership of the slag at the point of discharge or process for a fee and/or market the finished product and pay royalties to the steel company on sales. Some steel companies may allow the processor to share in royalties on these sales. Although there are many variations in the way a particular slag processor and steel mill will set up their

agreement, two possible options are considered here. The slag company may be paid to haul and transport the slag, process it, and market the finished product. The steel company, in turn, receives a royalty on the completed sale and a purchase discount on material recycled to the mill. In a minority of the contracts, the slag processor takes ownership of the material and pays little or no royalties to the mill. In this situation, the slag processor would be assuming 100% of the site development and capital costs, including facilities for screening, metallic separation, and crushing and heavy equipment, such as slag pot haulers, to move the material around.

Technology

Processing.—Slag processing systems include those outlined below, in A.W. Cooper's "Slag Handling in the Ironmaking Industry."

Pit Granulation.—Molten slag is poured, either from a slag ladle or directly from the furnace, into a pit filled with water, or is hit with sprays of water to rapidly quench it. The blast furnace slag forms granules that have a glassy or vitrified structure. The slag granules are then separated from the granulation water and transported to the drying and grinding plant.

Gravel Layer Filter Bed System.—Pit granulation is developed further with the gravel layer filter bed system. The slag is granulated at the furnace in a granulation head by high-pressure water sprays. The slag slurry flows down a runner to an agitating tank where water is injected to keep the slag in suspension. The slag is dewatered and then excavated by a computer-controlled bucket crane. The gravel layer filter bed keeps the water in the system in a closed circuit thus preventing water pollution. Atlantic Cement (now Blue Circle) has operated a gravel layer system since 1981.

Filter Hopper System.—Filter hopper systems use large dewatering silos lined with screens to dry the slag. This system extends the filtering system upward to conserve plant space. However, since the filtering is less efficient in the filter hopper system, pumping the slurry is necessary in the filter hopper.

Slag Pelletizer.—The slag pelletizer was developed by National Slag Ltd. in Hamilton, Ontario, as a means of bringing very high hydrogen sulfide gas emission levels typical of the "pit foaming" process under control.⁶ Pelletized slag is produced by expanding molten blast furnace slag under water sprays and then passing the flow of this pyroplastic material over a spinning drum on which fins are mounted. The fins break up the slag, which then forms into pellets owing to surface tension. While previous expanding processes have been of the batch type, this is a continuous process so that gaseous emissions are effectively diluted by generation over a long period of time. Because of this rapid cooling, the pelletizer can be thought of as an "air granulator."

The pelletizer has been installed in at least eight countries. Currently in Canada, about 400,000 mt of slag is pelletized annually and separately ground for use as a cementing material by the St. Lawrence Cement Co., Lafarge Canada Inc., and St. Mary's Cement. The pelletizers are installed near Hamilton, Ontario, where the major steel producers are located.

Operating Factors

Environmental Requirements.—Slag processors have had to be aware of environmental considerations, in much the same manner as have other mineral processing or manufacturing industries. During the past decade, concerns about the environment as embodied in the Clean Air Act of 1990 or Solid Waste and Clean Water legislation have grown. Concurrently, recycling and reuse of materials have become firmly established.

In keeping with public and private emphasis on improving the environment and preventing environmental harm, the slag industry has taken an active stance toward environmental responsibility in slag plant operations. Installation of new equipment, incorporation of improved operating procedures, and increased emphasis on such slag processing as slag granulation and other types of processing have all favorably impacted the slag industry.

At the same time, the emphasis on reuse of materials has meant that slag, which has been used as far back as Roman times, has been given renewed interest as a useful byproduct that serves as a substitute for mined aggregates. In addition, the use of slag as a commercial product is vastly more useful to the environment than it would be if it were landfilled.

Because of some of the different ways in which iron and steel slags can be utilized and the variety of steel slags available in the market, the slag processor can advise the user of iron and steel slags as to the best possible use for any given slag.

ANNUAL REVIEW

Legislation and Government Programs

On June 13, 1991, the EPA published its final regulatory determination, required by RCRA, for iron and steel slags and for 20 other special wastes from the processing of ores and minerals.⁷ The EPA concluded that regulation as a hazardous waste under subtitle C of RCRA is inappropriate for iron and steel slag and the other special wastes. The EPA planned to address iron and steel slags under subtitle D, possibly in the program being developed for mining wastes.

Pennsylvania Residual Waste Regulations were anticipated in early 1992 to expand the category of coproduct to include iron and steel slags after they were processed. Such slags, therefore, would no longer be considered waste products.⁸

Production

Koch Minerals Co., a division of Koch Industries of Wichita, KS, started up a grinding and granulation plant in June 1991 to process blast furnace slag produced from the Weirton Steel blast furnace, Weirton, WV. The grinding plant had a capacity of 180,000 mt, and the granulator has a capacity of 245,000 mt. Koch Minerals also started up the granulator at the USX Gary, IN, works in July 1991 and completed the cement grinding plant in December 1991.

The Levy Co. of Portage, IN, supplied expanded slag aggregate for the more than 900,000 lightweight concrete blocks used in building the new Comiskey Park stadium in Chicago, IL. (See cover photo of this report.) Chicago Block manufactured the blocks, and construction of the White Sox stadium was completed in early 1991.

Levy also supplied expanded slag for the 250,000 lightweight concrete blocks that were used in the Sears Corporate Headquarters, completed in 1991. Other buildings in the Chicago area that used expanded slag supplied by Levy were 900 N. Michigan, the Watertower Place, the Downtown Chicago Sheraton, City Front Center, and Ameritech Headquarters.

The Standard Slag Co., Eastern Div., based in Coraopolis, PA, supplied approximately 318,000 mt of slag for the new Greater Pittsburgh International Airport in 1991. Standard used air-cooled slag coarse aggregate extensively to construct the airport. The entire project was expected to be completed by 1992.

Consumption and Uses

If slag was not dug, crushed, screened, and sized, it would go to a disposal or processing facility. Moreover, use of various kinds of iron and steel slags can provide desirable features when used as construction aggregates and as a replacement for portland cement.

Sales of slag products generally reflected demand from the construction industry. The Department of Commerce reported that value of new construction

estimated in 1991 as \$380.4 billion declined by 6% compared with that of 1990.⁹ The value of highway and street construction was estimated to have increased slightly from 1990 to 1991.

Blast furnace slag can be used as a ground product to replace portland cement in concrete, as a special lightweight aggregate in blocks and highrise buildings, as a concrete aggregate replacing common concrete aggregates and sands, as a highly skid-resistant asphalt aggregate, and as a road base where the rough, interlocking surface and shape and cementitious properties enhance its load-bearing values.

Air-cooled blast furnace slag continued to be the predominant form of iron slag processed in the United States, accounting for more than 80% of blast furnace slag sales in 1991. The most significant end use in 1991 for air-cooled slag was as a road base. Air-cooled blast furnace slag was also used as an asphaltic concrete aggregate, fill, mineral wool, and glass manufacture. (See table 5 for related data.)

Consumption of combined expanded and granulated slag increased by approximately 80% from that of 1990 to 2,404,000 mt valued at \$43,484,000. Granulated slag was predominantly used in the manufacture of cement and expanded slag in the manufacture of lightweight concrete blocks.

Steel slag is principally used for highly skid-resistant asphalt road surfaces, road bases, and asphalt aggregates.

Reported steel slag consumption increased slightly compared with that of 1990 (see table 6). Steel slag used in asphaltic concrete and road bases increased moderately from that of 1990.

Transportation

Most slag is used within about a 50-kilometer radius of its source. Trucking costs make slag uncompetitive with mined aggregates when transportation distances exceed about 50 kilometers. Some slag may be delivered over greater distances to areas that do not have other aggregates for use in construction and roadbuilding.

Of all the iron and steel slag products sold in 1991, 85% traveled by truck, with an average marketing range of 45 kilometers; 4% traveled by waterway, with an average range of 404 km; and 3% traveled by rail, with an average range of 400 km. The remaining 8% was used at the plant where it was processed (see table 4).

Markets and Prices

The average price, f.o.b. plant, for all blast furnace slag was approximately \$8.27 per mt, approximately 20% more than that of 1990 (see table 7). The price of air-cooled blast furnace slag increased from \$5.67 to \$6.10 per mt in 1991. Granulated and expanded slag price information was withheld to avoid disclosing company proprietary data. The unit value for steel slag increased by 5% from that of 1990 to \$3.41 per mt.

Foreign Trade

Statistics developed by the U.S. Department of Commerce, Bureau of the Census, indicated that approximately 114,000 mt of granulated blast furnace slag was imported from Canada into the country during 1991. The 114,000 mt of Canadian imports reportedly entered into the country primarily through Buffalo, NY, Cleveland, OH and Baltimore, MD. The Canadian imports may be expanded or pelletized slag.

World Review

It is estimated that 40 million mt of slag is used annually.

In 1991 considerable interest was shown in many countries throughout the world to recycle and reuse materials produced in a wide range of metallurgical processes. Iron and steel slags have been among the mineral products thus reused.

Australia.—There are six blast furnaces in Australia, one in Whyalla, two in Newcastle, and three in Port Kembla. The latter produced approximately 7,000 mt of iron and 2,500 mt of slag per day. Approximately 3 to 4 million mt of slag was produced in Australia in 1991.¹⁰

Approximately 30,000 mt of granulated blast furnace slag was imported from Japan over the past 2 years. Granulated slag was exported to Hawaii, the Philippines, and Korea. A small amount of air-cooled blast furnace slag was sold to Malaysia for manufacture into wool insulation. There were three companies that generated steel slags, including two generating electric arc furnace slag.

According to the Australasian Slag Association, slag was not treated as a waste or considered hazardous in Australia; there were minimal environmental concerns with iron and steelmaking slags. It was expected that all slag generated in Australia would be used with the aim to add value to the slag.

Blast furnace slag cement marketed in Australia conformed to Australian Standard AS 1317. AS 1317 permitted slag to represent 20% to 65% of the total cementitious content.¹¹

BHP Steel of Melbourne, Australia, generated 2.0 million mt of blast furnace slag and 1.2 million mt of steelmaking slag from its three integrated steelmaking plants at Port Kembla, Newcastle, and Whalla. Approximately 800,000 mt of the blast furnace slags was granulated: 75% was used in cement production, 5% went to glass manufacture, and 20% went to construction sands. The remaining 1.2 million mt of blast furnace slag was air-cooled and marketed into aggregates and road construction.

The Australasian Slag Association sponsored various seminars in Port Kembla, New South Wales, including a Technical Seminar held in July 1991 and an Environmental Seminar held in September 1991. (See the Current Research section of this report.)

According to the Australasian Slag Association, a contract involving slag products was made in 1991 for the construction of piles and pile caps to be used in the tower foundations of the Glebe Island Bridge in Sydney, Australia. Marine cement containing 65% ground granulated blast furnace slag was used in the concrete. The State road authority, the Roads and Traffic Authority of New South Wales, proposed that the marine cement be used because of the harsh

environment and also to reduce heat of hydration.

The New South Wales State Rail Authority used 1.5 million mt of uncrushed air-cooled slag to stabilize land under the main rail link between Sydney and the South Coast of New South Wales.

Japan.—Thirty-six million mt of iron and steel slag was produced in Japan. Blast furnace slags were used as material for cement, aggregate for road and railroad construction, concrete mixing aggregate, material for building and building foundations, and for civil engineering. Eighty percent of the basic oxygen furnace slag and 65% of the electric arc furnace slag were used.

The Law for the Promotion of the Utilization of Recycled Resources was enacted on October 25, 1991.¹² Iron and steel slags were included in the category of industrial byproducts that were required to be reutilized under this law. Iron and steel slag was to be used as a raw material for cement and as a roadbed material. To efficiently use iron and steel slag, the ironmaking, steelmaking, and steel-rolling industries were to promote the manufacture of products from recyclable resources in accordance with standards and specifications, install facilities for effectively processing recyclable resources, and promote technological development that increases the use and improves the quality of recyclable resources. In Japan, a material that is reused is not considered to be a waste product.

Admixtures using blast furnace slag in cement for use in ready-mixed concrete have already been adopted into Japanese Industrial Standards.¹³

Korea, Republic of.—Keo Yang, an affiliate of Pohang Iron and Steel (POSCO), planned to process slags into powder for sale to Korean cementmakers.¹⁴ It opened a slag processing plant with an annual capacity of 600,000 mt at Kwangyang at a cost of 22.2 billion won. Korean cementmakers bought crude slag from POSCO for 11,000 won per mt, but powdered slag

cost 20,000 won per mt, excluding the transportation cost. Also, the Korean cementmakers were forced to use covered trucks for transportation of powdered slag and to establish storage facilities in their plants.

Netherlands.—A conference was held concerning the use of wastes in construction. (See Current Research section of this report.)

New Zealand.—According to the Australasian Slag Association, the New Zealand Government passed a Resource Management Bill on October 1, 1991. Use of renewable resources was promoted over new enterprises. Laws were also passed to control runoff from farms into streams and rivers. Blast furnace slag was the preferred material for these wetland filter beds required under the Resource Management Bill.

Blast furnace slag was cleared by the New Zealand Health Department as not containing free silica and was therefore suitable for grit blasting. Slag was also used for agriculture for crops such as kiwi fruit.

The demand for steel slag increased and it began to replace lime in the Auckland area. It was also used as a flocculent at mine sites to settle contaminated water and as a stabilizing agent.

Research was conducted using slag to neutralize toxic wastes.

United Kingdom.—It was estimated that 3 to 3.5 million mt of blast furnace slag was produced in the United Kingdom. This slag was either pelletized or granulated. The total capacity for granulation in the United Kingdom was approximately three-quarters of a million tons per year. The United Kingdom has five slag grinding plants operated by four companies. Two of the plants use pelletized slag and three use granulated slag. Of these three, one of the plants was commissioned in 1991. There are five blast furnace slag producing locations in the United Kingdom: Ravenscraig, Redcar, Scunthorpe, Port Talbot, and Llanwern. Slag from four of these was

processed for cementmaking. Approximately 400,000 mt of slag was imported.

The majority of ground granulated blast furnace slag was produced according to the British Standard 6699 for supply directly to the concrete manufacturer, ready-mixed, site-mixed, or precast for production of portland blast furnace cement concrete (PBFC). Small quantities were dry blended with portland cement and supplied in PBFC form.

A research report published in 1991 examined the supply of mineral and construction wastes, considered their suitability for use as construction aggregates, and suggested a tax on primary aggregates as a means of encouraging an increase in the use of waste material.¹⁵ Researchers examined blast furnace slag among other materials.

Current Research

Various seminars and conferences were held that focused on or included slag papers. The Australasian Slag Association held an International Seminar in July in Port Kembla, New South Wales, Australia, entitled, "Slag—the Material of Choice." "An Overview of Slag Usage in North America and Australia" by K.W. Spencer, Edw. C. Levy Co., Detroit, MI, discussed slag production in North America and Australia. Dr. Vute Sirivivatnanon of CSIRO, North Ryde, New South Wales, Australia, in "Durability Performance of Blast Furnace Slag Blend Concrete Structures" included a discussion of the long-term durability performance of concrete structures built of portland cement and binder systems that incorporated slag as well as the visual appearance, chloride diffusion and carbonation characteristics, and the reinforcing steel corrosion behavior of the sampled structural elements. Kevin Maw of the Slag Reduction Co. Ltd. in Rotherham, England, examined the successful utilization of steelmaking slag for more than 99 years by Steel Reduction Co. "Steel Slag—Its Use and Development in the United Kingdom by the Slag Reduction Co." is an excellent

primer covering the ways of making and cooling iron and steel slags with emphasis on steel slag formation. Steelworks and roads surfaced with steel slags in the United Kingdom were listed. K.P. Woodbury of the Wollongong Division Roads and Traffic Authority (RTA), New South Wales, presented "Trials and Use of Slag in Heavily Bound Pavements." The RTA tested a variety of slag pavement types that incorporated iron and steel slags. The RTA concluded that blast furnace slag can be used for high-quality road base, and slag or slag mixes could be used for heavily bound pavements provided that they are designed to take tensile strains. Because of the current trend toward heavily bound pavements due to lower costs for medium to heavily used roads, there is a need to determine what slag mixes would be suitable for these types of pavements.

The WASCON Conference was held November 10-14, 1991 in Maastricht, the Netherlands, to discuss the environmental implications of construction with waste.¹⁶ The use of various types of slags including foundry, incinerator, copper, and magnesium types was discussed in conjunction with road and other construction projects.

A number of studies carried out in 1991 highlighted the use of slag in waste disposal. Waste repositories for the below-ground disposal of low-level radioactive waste rely greatly on the durability of concrete for their required 500-year service life. A research program in Canada studied laboratory testing of concretes containing either Type 1 cement or cements containing 65% and 75% of blast furnace slag, each at four water-cement ratios.¹⁷ It has been established that the degradation of the concrete depended on the entrance rate of the corrosive agents, chlorides, sulfate ions, and CO₂. The improvements in concrete durability due to blast furnace slag additions were illustrated.

The application, development, design, installation, and operation of two electric arc furnaces to produce mineral wool were outlined at the electric furnace conference held in New Orleans, LA.¹⁸ These furnaces were supplied and

commissioned by Lectromelt and operate in Eastern Europe. Each produced up to 6.6 mt of melt per hour that was spun into mineral wool fibers for use as structural insulation. At this capacity, the furnaces were the largest mineral wool furnaces in the world that supplied vitrified melt to mineral wool spinners. Production from both furnaces was realized in 1985. The approximate production of the plant was 50,000 mt of mineral wool in 1988, and the expected production for 1989 was 60,000 mt. With the success of these furnaces, it was believed that this technology may not only be used by mineral wool manufacturers but could also be readily adapted to vitrify waste products.

The Nigerian steel industry has also attempted to alleviate the problem of waste disposal. Use of steel slag as an aggregate for concrete mixes and in powder form as a stabilizer for soil was investigated. The short-term results have encouraged further investigation.¹⁹

A large part of the research conducted in 1991 involved granulated blast furnace slag. Granulated blast furnace slag has been shown to be a useful component in forming blended cement in a study emphasizing world byproduct gypsum utilization.²⁰ When it reacted with gypsum in the presence of water, calcium sulfoaluminate hydrates (CSH) were easily formed, which functioned as a binder for concrete materials. The cement industry was able to use this property to manufacture supersulfate cement, expansive cement, and regulated-set cement. The main ingredients in slag-gypsum boards are 30% to 60% pulverized granulated blast furnace slag, 20% to 70% gypsum, and 5% to 15% fibrous materials. In addition, slaked lime or portland cement is added as an activator. Slag-gypsum boards are incombustible and water resistant.

The strength properties of triple-blend cements were studied at the Queensland University of Technology in Australia.²¹ Triple-blend cements are blends of ground granulated blast furnace slag, fly ash, and normal portland cement. Triple-blend stabilized road construction materials were able to withstand longer

periods of delay in compaction due to their slow strength gains. This phenomena made the stabilized material less susceptible to construction stoppages during base and subbase construction.

Work concerning steel slag blended cement (SSBC) and results of preliminary work utilizing Australian-produced steel slag were presented.²² The strength contribution, volumetric stability, and grindability of SSBC with and without incorporation of ordinary portland cement clinker were studied.

A research study used approximately 480,000 cubic meters of cemented materials to backfill mined-out stopes at one mine in Australia.²³ This was expected to increase in subsequent years. This study compared the potential strength development of binders containing granulated blast furnace slag with an existing fly ash/portland cement binder. It was shown that, based on binder performance, slag mixes can provide suitable strength development over the required time.

The effect of microsilica and blast furnace slag on pore solution composition and alkali silica reaction was studied at the King Fahd University of Petroleum and Minerals in Dhahran, Saudi Arabia.²⁴ Pore fluid analysis and 6-month expansion tests were carried out on plain, 10% and 20% microsilica, and 60% and 70% blast furnace slag cements. A few of the objectives were to study the correlation between expansions and hydroxide concentrations in the pore solution and alkali-removing capacity of blast furnace slag. Incorporation of 10% to 20% microsilica and 60% to 70% slag reduced expansions from nine times the permissible expansion to safe values ranging from one-tenth to one-half the allowable expansion. Although there are other concurrently occurring mechanisms in addition to alkali removal action, blast furnace slag was shown to be an active remover of alkalis and was especially effective in medium-alkali cements.

One study featured matrices including various cement replacement levels of ground granulated blast furnace slag (GGBFS), fly ash, and microsilica that had steel reinforcement electrodes

embedded in them.²⁵ The steel reinforcements were exposed to simulated marine splash zone exposure for about 600 days after initial curing in air for 14 days. The corrosion potentials and polarization resistance were monitored at regular intervals to determine the state and rate of corrosion. The results show that maximum protection against rebar corrosion is provided at 60% replacement of cement by blast furnace slag and at 10% and 15% replacement by microsilica.

Roller compacted concrete was being used increasingly as a material for concrete dam and concrete pavement. The construction method for these structures required no slump concrete because the concrete was transported by dump trucks and compacted by vibrating rollers. The usage of portland blast furnace slag cement has increased for concrete construction in Japan because the cement has contributed to energy saving and improvement of concrete durability. In a study carried out in Japan, the mixing tests for roller compacted concrete using the portland blast furnace slag cement were used to determine the optimum mix proportion by examination of various properties of concrete, such as flexural strength, length change, freeze-thaw cycle resistance, and fatigue strength.²⁶ Consequently, the use of portland blast furnace slag cement was found to be very effective as the cementitious material for roller compacted concrete. The exception to this was the case when early strength was required. The properties of the hardened roller compacted concrete were found to be very much influenced by the compaction degree of concrete.

To improve the durability of concrete, it has been recommended that blast furnace slag be incorporated into concrete. On the other hand, it can be expected that the use of a superplasticizer is effective to improve the workability of this type of concrete. A study at the Tottori University in Japan was conducted for the purpose of establishing appropriate mix designs for superplasticized concrete incorporating blast furnace slag, as well as for

understanding the properties of fresh and hardened concretes.²⁷ A superplasticizer and two types of high-range water-reducing agents were used in the study. The slag contents were 0%, 50%, and 70%. The effects of these additives were measured by slump test, rheological test, segregation test, and strength test, among others. The results showed that the flowability of cement paste increased with an increase in slag content. Also, the slump loss of superplasticized concrete increased with an increase in slag.

The properties of concretes containing instant-chilled steel (I.C.S.) slag as aggregate were studied at the University of Wollongong in Australia.²⁸ The I.C.S. slag possessed good physical and mechanical properties and had sufficient stability for use as a coarse aggregate in concrete. Compressive, indirect tensile and flexural strengths of I.C.S. slag concretes were greater than those of corresponding control concretes containing limestone aggregate.

Formulation and commercial utilization of solid waste incinerator slag byproduct was the focus of a research study carried out in Japan.²⁹ Particular attention was given to iron aluminosilicate melts having compositions similar to that of basalt. An ideal slag consumes flux additives at acceptable cost, is compatible with furnace refractory, flows readily from the furnace, and has physical properties suitable for its commercial utilization. Examples of successful solid waste slagging practice, including tonnage, utilization, and pricing, were provided from metallurgical and waste treatment operations of North America, Western Europe, and Japan.

Trial underwater concretes were prepared in Japan by mixing high-fineness slag with ordinary portland cement.³⁰ The strength development and segregation resistance properties of the concrete were studied for laboratory and concreting in site tests. The results of the tests were that the underwater concrete composed of ultra-high-fineness slag show good segregation resistance properties, good pumpability, high self-leveling, and good mechanical properties.

The Magnitogorsk Metallurgical Combine (MMK) in Magnitogorsk, U.S.S.R., developed a technology and perfected the production of building brick from granulated blast furnace slag and fireclay. Granular blast furnace slags from MMK had a low crystallization degree.³¹

Alkali-activated slag cement (AASC) was studied as a matrix for immobilization of radioactive wastes.³² Experimental results show that AASC is the best among other cements studied, and that AASC-based waste forms had high strength, low porosity, high resistance to chemical corrosion and to heat, and low solubility as well as leachability.

Kawasaki Steel Corp. in Japan developed a new pavement method with cement utilizing blast furnace slag.³³ A dry mixture, which consisted of crushed blast furnace slag, a volume of cement and water, was spread by an asphalt finisher and then compacted by a macadam or vibratory roller. This method, when used for surface course paving, radically reduced the duration of the construction period, including curing time, in comparison with the normal concrete paving method. The rigidity and strength also satisfied design requirements.

Commercial production of gold, silver, and copper from 1882 to 1984 at Mount Morgan, Queensland, Australia, resulted in the generation of blast furnace, reverberatory, and flash-furnace slags.³⁴ Large stockpiles on the order of 4 million tons of these slags were available at the site. The CSIRO Division of Building, Construction and Engineering was approached by Mount Morgan Ltd. to investigate the feasibility of using reverberatory slag in brickmaking and for making ceramic tiles. The results indicated that it was possible to use the reverberatory slag for making bricks and pavers from coarse slag-blended clay mixes and wall and floor tiles from fine slag-clay mixes, with the required physical properties. The products made from the coarse slag-clay mixes do not exhibit firing shrinkage if fired below the sintering temperature. The dense

products made from fine slag-clay mixes have relatively small shrinkage of 6% to 7%, very low values of apparent porosity and water absorption, and could be used without glazing in some tiling applications.

Slags generated by the ferrous metals industry can be used to produce high-value ceramic materials. The properties of these ceramics can be controlled by composition, additives, and processing parameters. Standard methods of materials handling, such as comminution, and mixing are as applicable to slag as to any other mineralogical raw material. In a study conducted in the U.S. Army Materials Technology Laboratory, foundry slag was ground, homogenized, melted, and formed to produce a glass and then heat-treated to crystallize it into a high-strength glass ceramic.³⁵ The product showed promise as a low-cost, wear-resistant tile material that could be custom cast. This and similar materials made from slags could be used as construction materials, acid-resistant piping, and shock-resistant sheathing.

OUTLOOK

Production of blast furnace slag and steel slag is expected to rebound after a slight decrease in 1991, owing to increased iron and steel production. (See Iron and Steel Annual Report, 1991.)

The ratio of granulated slag tonnage to all blast furnace slag is expected to grow due to environmental and cost considerations.

Electric arc furnace slags are expected to increase and other steel slags to decrease proportionately. The last open hearth furnaces closed in 1991, and large integrated steelworks may be faced with more competition from minimills, which use scrap, thus leading to a higher ratio of electric arc furnace slag to basic oxygen furnace slag.

There is a continued trend for slag companies to be a part of larger domestic and international companies that are diversified in construction and other industries. These larger companies can use the slag for their own downstream markets as well as provide support to the

slag processors with respect to environmental matters that are expected to increase in importance through the end of the decade and beyond. Marketing slag in higher value end uses such as in cement will continue to play an important role in the slag industry.

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**TABLE 1
IRON AND STEEL SLAGS SOLD OR USED¹ IN THE UNITED STATES**

(Thousand metric tons and thousand dollars)

Year	Blast furnace slag						Steel slag		Total slag ³	
	Air-cooled		Expanded ²		Total iron slag ³		Quantity	Value	Quantity	Value
	Quantity	Value	Quantity	Value	Quantity	Value				
1987	13,106	65,943	1,609	33,750	14,715	99,693	4,548	15,787	19,263	115,480
1988	12,920	69,415	1,504	32,139	14,424	101,554	5,184	18,058	19,608	119,614
1989	12,504	66,574	1,548	29,143	14,051	95,717	6,691	24,056	20,743	119,772
1990	13,741	77,863	1,315	26,448	15,057	104,311	6,851	22,268	21,908	126,578
1991	10,889	66,393	2,404	43,484	13,293	109,877	6,959	23,732	20,252	133,609

¹Value based on selling price at plant. Includes estimated value data for several operations.

²Includes granulated to avoid disclosing company proprietary data.

³Data may not add to totals shown because of independent rounding.

**TABLE 2
BLAST FURNACE SLAGS SOLD OR USED IN THE UNITED STATES, BY REGION AND STATE**

(Thousand metric tons and thousand dollars)

Region and State	1990				1991			
	Air-cooled, screened and unscreened		Total, all types		Air-cooled, screened and unscreened		Total, all types	
	Quantity	Value ¹	Quantity	Value ¹	Quantity	Value ¹	Quantity	Value ¹
North Central:								
Illinois, Indiana, Kansas, Michigan								
Ohio	8,539	44,733	9,077	48,882	6,163	37,142	6,593	40,241
Middle Atlantic:								
Maryland, New York, West Virginia	W	W	W	W	W	W	W	W
Pennsylvania	2,441	17,991	2,623	20,628	1,982	15,002	2,137	17,171
Total ²	W	W	W	W	W	W	W	W
Undistributed ²	2,761	15,139	3,357	34,802	2,744	14,249	4,565	52,465
Grand total ³	13,741	77,863	15,057	104,311	10,889	66,393	13,293	109,877

W Withheld to avoid disclosing company proprietary data; included in "Total and Undistributed."

¹Value based on selling price at plant.

²Includes Alabama, California, Colorado, Kentucky, Texas, Utah, and that indicated by symbol "W."

³Data may not add to totals shown because of independent rounding.

TABLE 3
PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1991

Company	Plant location	Iron blast furnace	Slag source			Blast furnace slag type
			Steel		Electric arc furnace	
			Basic oxygen furnace	Open hearth		
Alexander Mill Services	Blytheville, AR				X	—
Do.	Kankakee, IL				X	—
Do.	Charlotte, NC				X	—
Do.	Auburn, NY				X	—
Do.	Hubbard, OH				X	—
Do.	Holsopple, PA				X	—
Do.	New Castle, PA				X	—
Do.	Penn, PA				X	—
Do.	Washington, PA				X	—
Do.	Cayce, SC				X	—
Do.	Seguin, TX				X	—
Do.	Plymouth, UT				X	—
American Aggregates	Middletown, OH	X				Air-cooled.
Do.	New Miami, OH	X				Do.
Blue Circle Atlantic Inc.	Sparrows Point, MD	X				Granulated.
Buffalo Crushed Stone	Buffalo, NY	X				Air-cooled.
Dunbar Slag Co. Inc	Wheatland, PA	X	X	X		Do.
Fritz Enterprises Inc.	Lorain, OH	X				Do.
Heckett Co.	Fontana, CA		X			—
Do.	Chicago, IL	X				Air-cooled and expanded.
Do.	Sterling, IL				X	—
Do.	Indiana Harbor, IN		X			—
Do.	Ashland, KY	X	X			Air-cooled.
Do.	Coalton, KY				X	—
Do.	Newport, KY				X	—
Do.	Owensboro, KY				X	—
Do.	Kansas City, MO				X	—
Do.	Jackson, MS				X	—
Do.	Charlotte, NC				X	—
Do.	Canton, OH				X	—
Do.	Mansfield, OH				X	—
Do. (Warren Plant)	Warren, OH		X			—
Do.	Warren, OH				X	—
Do.	Youngstown, OH				X	—
Do.	Butler, PA				X	—
Do.	Fairless Hills, PA			X		—
Do.	Johnstown, PA				X	—
Do.	Geneva, UT	X		X		Air-cooled.
Do.	Kent, WA				X	—
Do.	Seattle, WA				X	—
Hempt Bros. Inc.	Steelton, PA				X	—
International Mill Service	Fort Smith, AR				X	—
Do.	Pueblo, CO		X			—
Do.	Claymont, DE				X	—
Do.	Tampa, FL				X	—
Do.	Cartersville, GA				X	—

See footnotes at end of table.

TABLE 3—Continued
PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1991

Company	Plant location	Iron blast furnace	Slag source			Blast furnace slag type
			Basic oxygen furnace	Open hearth	Electric arc furnace	
International Mill Service—Continued						
Do.	Alton, IL				X	—
Do. (South Works)	Chicago, IL		X			—
Do.	Granite City, IL		X			—
Do.	Huntington, IN				X	—
Do.	Laplace, LA				X	—
Do.	Baltimore, MD				X	—
Do.	Jackson, MI				X	—
Do.	Monroe, MI				X	—
Do.	St. Paul, MN				X	—
Do.	Perth Amboy, NJ				X	—
Do.	Riverton, NJ				X	—
Do.	Marion, OH				X	—
Do.	Middletown, OH		X		X	—
Do.	Mingo Junction, OH		X		X	—
Do.	Sand Springs, OK				X	—
Do.	Beaver Falls, PA				X	—
Do.	Burgettstown, PA				X	—
Do.	Coatesville, PA				X	—
Do.	Midland, PA				X	—
Do.	Pricedale, PA		X		X	—
Do.	Reading, PA				X	—
Do.	Georgetown, SC				X	—
Do.	Jackson, TN				X	—
Do.	Beaumont, TX				X	—
Do.	El Paso, TX				X	—
Do.	Jewett, TX				X	—
Do.	Longview, TX				X	—
Do.	Midlothian, TX				X	—
Do.	Weirton, WV					—
Koch Minerals	Gary, IN	X				Air-cooled, expanded and granulated.
Do.	Weirton, WV	X				Granulated.
C.J. Langenfelder & Son Inc.	Braddock, PA		X			—
Edward C. Levy Co.	Detroit, MI	X	X		X	Air-cooled and expanded.
The Levy Co. Inc.	Burns Harbor, IN	X	X			Air-cooled.
Do.	East Chicago, IN	X	X			Do.
Maryland Slag Co.	Sparrows Point, MD	X				Do.
Sheridan Corp.	Lebanon, PA	X				Do.
Standard LaFarge Co.	Granite City, IL	X				Do.
Do.	Cleveland, OH	X				Do.
Do.	Cuyahoga, OH				X	—
Do.	Lordstown, OH	X			X	Granulated.
Do.	McDonald, OH	X			X	Air-cooled.

See footnotes at end of table.

TABLE 3—Continued
PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1991

Company	Plant location	Iron blast furnace	Slag source			Blast furnace slag type
			Steel			
			Basic oxygen furnace	Open hearth	Electric arc furnace	
Standard LaFarge Co.—Continued:						
Do.	Mingo Junction, OH	X				Air-cooled.
Do.	Warren, OH	X				Do.
Do.	Penn Hills, PA			X		—
Do.	West Alliquippa, PA	X	X			Air-cooled.
Do. (Brown Reserve)	West Mifflin, PA	X				Do.
Do. (Duquesne)	West Mifflin, PA	X		X		Do.
Do.	Weirton, WV	X				Do.
Stein, Inc.	Cleveland, OH		X			—
Do.	Lorain, OH		X			—
United Slag Co.	Rancho Cucamonga, CA				X	—
Do.	McMinnville, OR				X	—
Vulcan	Alabama City, AL	X	X			Air-cooled.
Do.	Fairfield, AL	X	X			Do.
Warner Co.	Bala-Cynwyd, PA	X				Air-cooled and expanded.
Waylite Corp.	Bethlehem, PA	X	X			Do.

TABLE 4
SHIPMENTS OF IRON AND STEEL
SLAG IN THE UNITED STATES IN
1991, BY METHOD OF
TRANSPORTATION

Method of transportation	Quantity (thousand metric tons)
Truck	17,156
Waterway	829
Rail	675
Not transported (used at plant site)	1,593
Total	20,252

¹Data do not add to total shown because of independent rounding.

TABLE 5
AIR-COOLED BLAST FURNACE SLAG SOLD OR USED IN THE UNITED
STATES, BY USE¹

(Thousand metric tons and thousand dollars)

Use	1990		1991	
	Quantity	Value	Quantity	Value
Asphaltic concrete aggregate	1,938	12,049	1,634	9,577
Concrete aggregate	1,615	10,405	1,333	9,683
Concrete products	430	2,557	358	2,333
Fill	1,414	5,844	855	3,950
Glass manufacture	W	W	W	W
Mineral wool	527	3,614	449	3,056
Railroad ballast	³ 360	2,024	221	1,288
Road base	6,955	36,827	5,339	30,282
Roofing, buildup and shingles	71	726	68	771
Sewage treatment	W	W	W	W
Soil conditioning	W	W	W	W
Other ²	432	3,817	633	5,455
Total³	13,741	77,863	10,889	66,393

W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Value based on selling price at plant.

²Includes ice control, miscellaneous, and uses indicated by symbol W.

³Data may not add to totals shown because of independent rounding.

TABLE 6
STEEL SLAG SOLD OR USED IN THE UNITED STATES, BY USE¹

(Thousand metric tons and thousand dollars)

Use	1990		1991	
	Quantity	Value	Quantity	Value
Asphaltic concrete aggregate	967	3,153	1,085	4,617
Fill	912	3,510	828	2,374
Railroad ballast	206	621	186	585
Road bases	2,887	8,901	3,238	10,625
Other ²	1,879	6,081	1,623	5,531
Total³	6,851	22,268	6,959	23,732

¹Excludes tonnage returned to furnace for charge material. Value based on selling price at plant.

²Includes ice control, soil conditioning, and miscellaneous uses.

³Data may not add to totals shown because of independent rounding.

TABLE 7
AVERAGE VALUE PER TON AT THE PLANT FOR IRON AND STEEL SLAG SOLD OR USED IN THE UNITED STATES, BY TYPE

(Dollars per metric ton)

Year	Iron blast furnace slag			Total iron slag	Steel slag	Total slag
	Air-cooled	Granulated	Expanded			
1987	5.03	W	W	6.78	3.47	5.97
1988	5.37	W	W	7.04	3.48	6.04
1989	5.32	W	W	6.81	3.59	5.78
1990	5.67	W	W	6.92	3.25	5.78
1991	6.10	W	W	8.27	3.41	6.60

W Withheld to avoid disclosing company proprietary data.

TABLE 8
AVERAGE SELLING PRICE AND RANGE OF SELLING PRICES AT THE PLANT
FOR IRON AND STEEL SLAG IN THE UNITED STATES IN 1991, BY USE

(Dollars per metric ton)

Use	Iron blast furnace slag						Steel slag	
	Air-cooled		Granulated		Expanded		Average	Range
	Average	Range	Average	Range	Average	Range		
Asphaltic concrete aggregate	5.32	2.44- 9.71	—	—	—	—	3.86	2.75- 6.67
Cement manufacture	W	W	W	W	—	—	—	—
Concrete aggregate	6.59	3.08-10.00	—	—	—	—	—	—
Concrete products	5.92	3.90-10.00	—	—	W	W	—	—
Fill	4.19	1.46- 8.24	—	—	—	—	2.60	1.05- 5.00
Glass manufacture	W	W	—	—	—	—	—	—
Lightweight concrete aggregate	—	—	—	—	W	W	—	—
Mineral wool	6.17	5.00- 9.01	—	—	—	—	—	—
Railroad ballast	5.29	3.88- 8.45	—	—	—	—	—	—
Road bases	5.15	3.05- 8.00	W	W	—	—	2.98	.65- 5.96
Roofing, builtup and shingles	10.26	5.33-14.00	—	—	—	—	—	—
Sewage treatment	W	W	—	—	—	—	—	—
Soil conditioning	W	W	W	W	—	—	W	W
Other	5.25	2.00- 8.50	—	—	—	—	3.05	1.03-19.14

W Withheld to avoid disclosing company proprietary data.

SODA ASH

By Dennis S. Kostick

Mr. Kostick, a physical scientist with 13 years of U.S. Bureau of Mines experience, has been the commodity specialist for soda ash since 1979. Domestic survey data were prepared by Carleen Militello, statistical assistant; and international data tables were prepared by William Zajac, Chief, Section of International Data.

Continuing with this report, all data are reported in metric units in order to comply with Public Law 100-418 of August 23, 1988. This Federal law requires all Federal agencies to use the metric system of measurement by the end of fiscal year 1992. Although the use of the metric measurement standards was authorized by law since 1866 (Act of July 28, 1866; 14 Stat. 339) and the United States was an original signatory party to the 1875 Treaty of the Meter (20 Stat. 709), the United States has been the only industrially developed nation that has not universally converted to the metric system from the English system of measurements. As foreign trade of soda ash increases and foreign participation in U.S. joint ventures continues, communicating information with an international standard of measurement becomes more important.

DOMESTIC DATA COVERAGE

U.S. soda ash production data are collected by the U.S. Bureau of Mines from monthly, quarterly, and annual voluntary surveys of U.S. operations. Of the six soda ash operations to which a survey request was sent, all responded, representing 100% of the total production data shown in this report.

Data pertaining to soda ash consumption by end use is collected quarterly from the industry. Trade statistics are obtained from the U.S. Department of Commerce, Bureau of the Census. The export data collected by the Census Bureau may not correspond to the export data provided by the soda ash

producers in the quarterly survey of soda ash sales. The discrepancy between the export data sets is because Census data reports the transaction on the date the cargo physically departed from the U.S. port whereas soda ash producers consider a shipment as exported when it leaves the plant. Overland transit time between the plant and port and any carryover export inventory are not taken into consideration.

Most people have never heard of soda ash, yet it is used in many familiar consumer products found in virtually every home—glass, soap and detergents, paper, textiles, and food. Chemically, soda ash is known as sodium carbonate. It is the 11th largest inorganic chemical in terms of production of all domestic inorganic and organic chemicals, excluding petrochemical feedstocks. Internationally, there are two types of soda ash—natural and synthetic. The United States is the world's largest soda ash-producing nation with the world's largest natural deposit of trona, the ore from which soda ash is refined. Because the majority of world output is made synthetically, which usually is more expensive to manufacture, U.S. natural soda ash is extremely competitive in world markets. (See table 1.)

BACKGROUND

Although soda ash represented about 2.4% of the total \$35 billion nonfuel mineral industry that was surveyed by the U.S. Bureau of Mines in 1991, its use in many familiar household products consequently contributes substantially to

the gross national product of the United States. Soda ash is one of the basic inorganic chemicals produced in the world. Most countries do not have economic deposits of sodium carbonate-bearing minerals and must produce soda ash by various manufacturing techniques, which are labor-, capital-, and energy-intensive. In addition, the processes generate byproduct sodium chloride and calcium chloride, which are usually discharged as waste effluent that contribute to environmental problems.

Natural soda ash was probably first obtained as evaporite incrustations along the edges of alkaline lakes in Lower Egypt. It was used about 3,500 B.C. to make ornamental glassware, as evidenced by many of the early Egyptian glass artifacts. The Egyptians also mixed lime and soda ash to make caustic soda. The caustic soda was combined with silicate minerals obtained from the Sinai desert. This made a soluble silica, which was added to aluminum-rich Nile River silt, producing a silica-aluminate cement mortar with superior bonding properties. In the Old Testament, it was referred to as neter but has also been known as natrium, kali, trona, and natron. Until the 18th century, soda ash was obtained mainly by burning seaweeds and marine plants, leaching the soluble material from the ashes, and evaporating the solutions to dryness. About 13 tons of ash yielded 1 ton of sodium carbonate and 14 kilograms (30 pounds) of iodine as a byproduct. The final material was very impure but could be used in the manufacture of glass and soap and detergents. Pliny, a Roman historian,

listed soda ash in the manufacture of glass, as a medicine for colic pains and skin eruptions, and for making bread in the first century A.D.

In 1791, Nicolas Leblanc, a French chemist, developed a process for making soda ash from "salt cake" (from salt and sulfuric acid), coal, and limestone. The French Revolution interfered with its development, and his patent and factory were confiscated with him receiving only token compensation. Napoleon returned his factory to him but Leblanc was not able to raise enough capital to reopen it, and he committed suicide in 1806. More than 30 years passed before the process first became successful in Liverpool, England. The process was not used successfully in the United States except during a short period from July 1884 to January 1885 at Laramie, WY.

Ernest and Alfred Solvay developed an improved method for making soda ash from salt, coke, and limestone, with ammonia as a catalyst in the early 1860's. That process was first used in the United States in 1884 at Syracuse, NY, in a plant that continued to produce soda ash until 1986. It was the first of about 10 synthetic Solvay plants that were in operation by 1939 in the United States, and, ironically, the last one to close. The Solvay process gained in popularity over the years and is now the basic method used throughout the world for making synthetic soda ash. In addition to the Solvay plants, there were three electrolytic process plants in Tyrone, PA, Covington, VA, and Luke, MD, that were operated by West Virginia Pulp and Paper Co. in 1939.

The site of the first commercial production of natural soda ash in the United States was from two deposits known as the Soda Lakes near the present town of Fallon, NV. Asa L. Kenyon acquired title to Little Soda Lake in 1855 and sold it to Higgins and Duffy in 1868, when the first 300 tons of natural soda ash was produced. Production of adjacent Big Soda Lake began in 1875 and reached its peak in 1887. The brines became diluted as the lake levels rose in 1907 because regional dam construction affected the local water table. Searles

Lake in California was originally mined for borax as early as 1874. Soda ash production began in 1926 by the West End Chemical Co. American Potash Corp., formerly the American Trona Corp., was the second company to produce soda ash at Searles Lake in 1931. (See figure 1.)

Definitions, Grades, and Specifications

The following terms are used in the soda ash industry:

Ammonia-Soda Process.—Also known as the Solvay process and lime-soda process.

Dense Soda Ash.—Has a bulk density of 0.96 to 1.06 grams per cubic centimeter (60 to 66 pounds per cubic foot). It is produced by hydrating light soda ash followed by dehydration through calcination to produce denser crystals. In Eastern Europe, dense ash is made by compressing light ash between rollers to increase the density, followed by screening.

Light Soda Ash.—Has a bulk density of 0.51 to 0.62 grams per cubic centimeter (32 to 39 pounds per cubic foot). It is produced by calcining the sodium sesquicarbonate precipitate recovered from the carbonation towers or vacuum crystallizers.

Natural Soda Ash.—Soda ash produced from trona ore, sodium carbonate-bearing brines, or surface mineralization.

Soda Ash.—Synonymous with sodium carbonate. It is a general term that can apply to soda ash produced from natural sources or from various chemical processes.

Sodium Sesquicarbonate.—Can refer to the name for the chemical composition of trona or the chemical process that produces a light- to intermediate-grade of soda ash having an average bulk density

of 0.8 gram per cubic centimeter (50 pounds per cubic foot).

Synthetic Soda Ash.—Term for soda ash produced from one of several chemical processes, such as the Solvay process.

Trona.—The principal ore from which soda ash is made. It is composed of sodium carbonate, sodium bicarbonate, and water. The monoclinic crystals are prismatic to tabular, with colors ranging from translucent (spar variety) to shades of brown, which vary depending on the amounts of contained organic matter. Trona has a specific gravity of 2.17 with a hardness of 2.5 to 3 on the Mohs scale. About 1.8 tons of trona is required to produce 1 ton of soda ash.

The terms "soda ash" and "sodium carbonate" are used interchangeably. The material manufactured from Wyoming trona normally contains more than 99.8% sodium carbonate, and the sodium chloride content ranges between 0.01% to 0.02%. The amount of iron is less than 10 parts per million. Searles Lake brines are processed to yield a product of similar high quality, with salt and sodium sulfate as the principal trace impurities. The average material produced by a Solvay soda ash plant is about equal to the natural product in sodium carbonate content, but often contains a larger quantity of salt. Dense soda ash, because of its greater bulk density, may command a higher price than the light variety and is preferred for glass manufacture because the light soda ash leads to frothing in the glass melt. Light soda ash is preferred by many chemical and detergent industries because it dissolves more readily. Sodium sesquicarbonate has an intermediate bulk density and is used in some detergent and bath salts.

Typical official specifications for soda ash include American National Standard K60, 11-1956 (R1969) "Standard Specifications for Soda Ash," which appears as the American Society for Testing and Materials (ASTM) Designation D458-74 (Reapproved 1979); and British Standard (BS) 3674: 1963 "Specification for Sodium Carbonate

(Technical Grades)." The British Standard specifies, among other requirements, not less than 57.25% Na₂O and not more than 0.005% Fe₂O₃; the ASTM, a minimum of 99.16% Na₂CO₃. Both standards specify methods of testing.

Industry Structure

The U.S. soda ash industry is composed of six companies; five in Wyoming and one in California. All produce natural soda ash only either from sodium carbonate-rich brines or from underground mining of trona ore. Foreign investment in U.S. soda ash operations has risen from 10% of capacity in 1981, when Societe Nationale Elf Aquitaine of France bought Texasgulf Chemical Co., to 37% in 1991. Five of the six U.S. companies have either Australian, French, Japanese, or Korean partners. FMC remains the only U.S. producer without any foreign ownership. (See tables 2 and 3.)

Geology-Resources

The definitions of resources, reserves, and reserve base are published in U.S. Geological Survey Circular 831, Principles of a Resource/Reserve Classification for Minerals. Briefly, "resources" describe the quantity of ore present, regardless of grade or ease of extraction. The "reserves" are the portion of the resource that are economic to mine using the current technology and value of the commodity.

There are more than 60 identified natural sodium carbonate deposits in the world, the largest of which is the trona deposit in southwest Wyoming. Although several of these deposits have been quantified, most are economically insignificant or too remote to be commercially developed. Table 3 lists the countries with known soda ash deposits. All soda ash deposits can be classified in one of five modes of occurrences. In decreasing order of economic importance, they are as follows: buried, surface or subsurface brines, crystalline shoreline or

bottom crusts, shallow lake bottom crystals, and surface efflorescences.

The trona found in the Green River Formation in southwest Wyoming is an excellent example of a buried trona deposit. The Wilkins Peak Member contains 42 beds of trona, 25 of which have a thickness of 0.91 meter (3 feet) or more. Eleven of these exceed 1.83 meters (6 feet) in thickness covering an area more than 3,100 square kilometers (1,200 square miles). The trona beds were deposited about 50 million years ago in the early to middle Eocene epoch in an ancient freshwater lake, named "Lake Gosiute" by Clarence King in 1878. The sodium and carbonate constituents of trona owe their respective origins to the leaching of the extensive pyroxene-andesite volcanic ash layers and the seasonal influxes of carbonate-rich sediments into the local depositional basin. In addition, subterranean thermal springs contributed a significant quantity of dissolved alkaline carbonates as well as sodium, calcium, silica, and bicarbonate ions. Trona can precipitate only in the presence of abundant carbon dioxide, which probably was supplied from the atmosphere and/or the biogenic decay of Eocene plant and aquatic remains. For 4 million years, Lake Gosiute went through many stages of filling and evaporation, thereby depositing more than 42 beds of trona on the lake bottom along with repetitive beds of marlstone, limestone, oil shale, and sandstone-mudstone. The decrease of the inflow to the lake was probably in response to climatic changes that resulted in the final evaporation of the waters. The former Lake Gosiute is the present Green River Basin.

Assuming 1.8 tons of trona yields approximately 1 ton of soda ash, about 47 billion tons (52 billion short tons) of identified soda ash resources could be obtained from the 56 billion tons (62 billion short tons) of bedded trona and the 47 billion tons (52 billion short tons) of interbedded or intermixed trona and halite that are in beds greater than 1.22 meters (4 feet) thick. Approximately 34 billion tons (37 billion short tons) of reserve base soda ash could be obtained from the 36 billion tons (40 billion short tons) of

halite-free trona and the 25 billion tons (27 billion short tons) of interbedded or intermixed trona and halite in beds more than 1.83 meters (6 feet) thick. Although about 15 million tons (16 million short tons) of trona is presently being mined annually, with these minable reserves Wyoming could supply all domestic requirements for more than 3,100 years at the 1991 demand level. As technology improves in the future, mining of the subeconomic grades of ore would further extend the life of the trona deposit to more than 5,100 years. With Wyoming reserves estimated at 20 billion tons (22 billion short tons), the United States, through this one deposit, could supply the world all the soda ash to meet the current demand levels for about 630 years. (See table 4.)

The U.S. Government established a Known Sodium Leasing Area (KSLA) in Wyoming within the perimeter of the trona depositional basin. The trona within the KSLA is subject to Federal and State leasing regulations and private lease agreements. Although most of the leasable trona averages 93% sodium sesquicarbonate, several areas contain lower grade trona because of local depositional contamination along the lake margins, thereby reducing the reserve estimates of that particular area.

A series of Pleistocene playa lakes rich in evaporate minerals found in California comprise the second largest reserves of sodium carbonate in the United States. Subsurface sodium carbonate-bearing brines and crystalline material comprise the resource at Searles Lake, which is a nearly dry playa 15 kilometers (9 miles) long by 11 kilometers (7 miles) wide with an area of about 104 square kilometers (40 square miles). Surface sodium-bearing crystalline minerals predominate at Owens Lake, which was first mined in 1885 by the Inyo Development Co. Both deposits have combined reserves of about 817 million tons (900 million short tons).

Two potential sources of soda ash—nahcolite (natural sodium bicarbonate) and dawsonite (sodium-aluminum-carbonate)—are associated with oil shale in the Piceance Creek basin in northwest Colorado. Identified resources of 29

billion tons (32 billion short tons) of nahcolite and 17 billion tons (19 billion short tons) of dawsonite, equivalent to 18 billion tons and 6 billion tons (20 billion short tons and 7 billion short tons), respectively, of sodium carbonate resources, would be available as a byproduct of oil shale processing or as single mineral extraction. These deposits were formed in middle Eocene time with the nahcolite occurring as aggregates (62%), disseminated crystals (24%), and impure beds (14%).

The only other commercial natural soda ash deposit in the Western Hemisphere, excluding those in the United States, occurs at Lake Texcoco, near Mexico City, Mexico. Two caliche layers at a depth of 46 meters (150 feet) act as a filter and reservoir for the sodium carbonate-rich brine resource. With an average concentration of about 7% sodium carbonate, the resource contains about 180 million tons (200 million short tons) of available soda ash.

The Rift Valley of eastern Africa has several alkaline lakes resembling those of California. Only Lake Magadi in Kenya is presently in production. The soda ash reserves of these lakes are renewed annually from natural active volcanic sources. Other African countries that may become future suppliers of soda ash are Chad, Ethiopia, Niger, the Republic of South Africa, Tanzania, and Uganda. Botswana is developing its Sua Pan salt and soda ash deposit, and final completion of the project is scheduled for 1991. Elsewhere, deposits of natural soda ash occur in Bolivia, Brazil, Canada, India, Pakistan, the U.S.S.R., and Venezuela. Plans are underway to develop deposits in China at Xilin Gol and in the Wulan Buh desert area. A trona deposit in Turkey near Beypazari is also under consideration for development.

Technology

Soda ash from Wyoming trona is mined, crushed, dried, dissolved, filtered, recrystallized, and re-dried. In California, soda ash from sodium carbonate-bearing brines is solution mined, carbonated,

filtered, dried, decomposed, bleached, and recrystallized to dense soda ash.

Exploration.—Because of the scarcity of economic soda ash deposits in the world, many nations continue to search for new prospects. Smaller and less well known deposits are often reevaluated by different groups at different times and with usually the same results. As new techniques of exploring are developed and used, such as Landsat satellite remote sensing imagery and side-scanning radar, new deposits may be discovered.

In the United States, exploring for soda ash continues. An area near the junction of the Black's Fork and Green River in southwest Wyoming has potential. Some of the ground water near Farson contains dissolved trona and organic matter creating a "black trona water." BWAB, a Denver-based company, planned to develop this area and extract the sodium carbonate from the black water and convert the organic material to fungicides, pesticides, and pigments.¹ In Oregon, a few companies have expressed interest in evaluating the sodium carbonate deposits at Summer Lake and Abert Lake, which are near several pulp and paper manufacturers. These manufacturers have traditionally obtained their soda ash and caustic soda pulp-bleaching chemicals from Wyoming and Washington producers, respectively. As soda ash and caustic soda prices increase and overland transportation costs rise, these Oregon deposits may have commercial significance because their locations are nearer to the pulp markets.

Mining.—Commercial mining of Wyoming trona began in 1948, with the first mining on Federal land commencing in 1950. Between 1950 and 1991, more than 223 million tons (245 million short tons) of trona (equal to about 134 million tons or 147 million short tons of soda ash) has been mined. Only about 0.6% of the 36 billion tons (40 billion short tons) of halite-free trona reserve base has been used since mining began.

Underground mining of Wyoming trona is similar to coal mining, except that trona is a harder mineral than coal. The

five present Wyoming soda ash producers use room-and-pillar, longwall, shortwall, and solution mining techniques individually or in combination. The room-and-pillar method has an ore extraction efficiency rate of about 45% (55% of ore remains as pillars for structural integrity), the longwall and shortwall methods each have efficiency rates of about 75%, and solution mining has an efficiency rate of about 30%. These rates are important when calculating the amount of reserves that are minable. Based on the types of mining techniques, the author used a 60% average extraction efficiency rate to calculate reserves (remaining 40% stays in-place as pillars for structural integrity and unavailable for present extraction). The ore is undercut, drilled, blasted, mucked, crushed, and transported to the surface by well-established methods and various state-of-the-art mining equipment. The conventional blasting method using prilled ammonium nitrate and fuel oil (ANFO) is a standard and reliable method. Continuous mining uses vehicles equipped with a rotating cylindrical cutter. Continuous miners are used by Tg Soda Ash, Inc., in its shortwall technique. The longwall technique was used by General Chemical Corp. and is now used by FMC Wyoming Corp. Adopted from coal mining use, the longwall method uses a special track-mounted shearer that moves in front of a hydraulic-operated roof support system.

FMC has pioneered the use of solution mining to dissolve and recover deeply buried trona. Using an array of injection and recovery wells, a solvent (dilute sodium hydroxide) is introduced under pressure to dissolve the underlying trona. This technique has had moderate success since its first commercial debut in 1985. Beginning in 1990, FMC used the majority of the output from its solution mining for manufacture of caustic soda, from which some sodium cyanide was produced.

To reduce mining costs and maintain their competitiveness in the world, many Wyoming soda ash companies implemented continuous belt and mobile track conveyor systems to transport trona

underground more efficiently. This new haulage system has replaced ore-carrying shuttle cars, reduced the mine work force, and increased the quantity of ore mined per shift. Companies have also been considering eliminating conventional mining but retaining other mining methods sometime in the foreseeable future in order to further reduce labor, safety, and other operating costs.

Subterranean brines between 15 and 107 meters (50 and 350 feet) below the surface at Searles Lake in California are extracted using an array of injection and recovery well drilled down to specific depths where mineral concentrations favor maximum extraction. The Argus plant of North American Chemical Co. uses sodium carbonate-rich brines found in the Mixed Layer zone 67 meters to 95 meters (220 feet to 310 feet) below the surface. Solar concentration ponds are used to aerate and concentrate the brine to improve processing efficiency.

Processing.—Crushed trona is calcined in a rotary kiln at 163° to 204° C (325° to 400° F) to dissociate the ore by the monohydrate process, which produces only dense soda ash with carbon dioxide and water as byproducts. The calcined material is combined with water to dissolve the soda ash and to allow separating and discarding of the insoluble material such as shale and shortite by settling and/or filtration. The waste material is piped in a slurry to containment basins, also known as tailing ponds. The resulting clear liquid is concentrated as necessary by triple-effect evaporators or mechanical vapor recompression crystallizers, and the dissolved soda ash precipitates as crystals of sodium carbonate monohydrate, $\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$. The crystallization temperature is about 100° C (212° F), which is below the transition temperature of monohydrate to anhydrous soda ash. Other dissolved impurities, such as sodium chloride or sodium sulfate, remain in solution. The crystals and liquor are separated by centrifugation. The sodium carbonate monohydrate crystals are calcined a second time at 300° F to remove water of crystallization.

The resultant finished product is cooled, screened, and shipped by rail or truck in bags or bulk.

An alternate method of soda ash production from trona is the sesquicarbonate process. Crushed trona is first dissolved and filtered to remove insoluble impurities. The liquor is evaporated in vacuum crystallizers, and the sodium sesquicarbonate precipitate is cooled to 38° C (100° F) and centrifuged to produce a pure product, which has uses as such. The sesquicarbonate can be further calcined at 204° C (400° F) to produce anhydrous soda ash of light to intermediate density.

The complex brines of the lower level of Searles Lake are first treated with carbon dioxide gas in carbonation towers to convert the sodium carbonate in solution to sodium bicarbonate, which will precipitate under these conditions. The sodium bicarbonate is separated from the remainder of the brine by settling and filtration and is then calcined to convert the product back to soda ash. The decarbonated brine is cooled to recover borax and Glauber's salt. A second dissolving, precipitating with carbon dioxide, filtering, and calcining the light soda ash to dense, refines the product to better than 99% sodium carbonate.

At Owens Lake in California, crude soda ash has been mined and processed by Lake Minerals Corp. by simply digging perimeter channels allowing the interstitial fluids to drain. The surface was tilled to promote evaporation to reduce moisture content, followed by harvesting with front-end loaders.

At Lake Magadi, Kenya, crude trona is dredged from surface crusts, crushed, washed, and calcined to convert the sodium sesquicarbonate to soda ash. At Lake Texcoco in Mexico, underground brines are recovered and sent to a surface spiral concentrator to promote the solar concentration of the sodium carbonate in solution. On the Kola Peninsula in the U.S.S.R., soda ash is recovered from processing nepheline-bearing rocks. Nepheline, a sodium-potassium-aluminum silicate, is calcined in rotary kilns to yield alumina, potash, and soda ash. The alumina content of the rocks is about one-

half of bauxite but the mining and processing produces byproduct soda ash. The Petukhi and Tanatar (Mikhaylovskiy) natural soda ash lakes in Altay Kray of West Siberia provide some source of natural product.

Synthetic soda ash using the Solvay process uses salt and limestone as raw materials. A purified sodium chloride brine is saturated with ammonia and carbon dioxide gas to produce ammonium bicarbonate, which reacts with the salt to form sodium bicarbonate and ammonium chloride. The sodium bicarbonate is calcined at 177° to 218° C (350° to 425° F) to light soda ash, and the gases produced are recycled back to the liquid phase. The liquid containing ammonium chloride is reacted with milk of lime to recover the ammonia and to produce byproduct calcium chloride. Limestone and coke are required to make the milk of lime. Dense soda ash is produced by hydrating light ash to produce larger sodium carbonate monohydrate crystals. The crystals are dehydrated in dryers to change the bulk density. To produce 1.0 ton of synthetic soda ash requires about 2.8 tons of steam, 1.7 tons of salt, 1.4 tons of limestone, 0.6 ton of coal for the boilers, and about 0.2 ton of coal for the dryers. Disposition of effluent streams containing high concentrations of calcium chloride and sodium chloride is a major problem for all Solvay soda ash plants. The Solvay process discharges about 1.7 tons of waste products that include sodium chloride and calcium chloride.

Other chemical processes can produce synthetic soda ash. The Japanese use an ammonium chloride coproduction process, a variation of the Solvay process, that converts all the sodium content of the salt into soda ash, whereas the Solvay process converts only about 70% of the sodium. The Japanese process also produces byproduct ammonium chloride that can be used as a fertilizer for growing rice in wetlands. The New Asahi process was also developed in Japan and uses less energy than the traditional Solvay process. An electrolysis-free process to produce vinyl chloride monomer with coproduct soda ash was developed in the Netherlands but

has not been in commercial operation. The method yields soda ash instead of caustic soda and uses steam and carbon dioxide instead of electricity. The energy consumption is reported to be one-half that of the Solvay process.

Recycling.—There is no recycling of soda ash by producers; however, many glass container manufacturers are using cullet glass, thereby reducing soda ash consumption.

Byproducts and Coproducts

Borax, potassium chloride, sodium chloride, and sodium sulfate are produced as coproducts with soda ash by North American Chemical in California. In Wyoming, only value-added products, such as sodium bicarbonate, sodium hydroxide (caustic soda), sodium sesquicarbonate, and sodium tripolyphosphate, are produced from trona ore. Soda ash-bearing purge liquors and waste streams, normally considered waste byproducts, have been sold to powerplants for flue gas desulfurization because of their sodium carbonate content.

Substitutes

Sodium hydroxide can be substituted for soda ash in some applications, but usually only at a higher cost and when available. About 1.3 tons of soda ash must be used to have the same chemical effect as 1.0 ton of caustic soda. Soda ash is usually shipped in dry, bulk form whereas caustic soda is transported as a liquid in various-sized closed containers.

An alternate source of soda ash is nahcolite, natural-occurring sodium bicarbonate found in a vast deposit in Colorado. The nahcolite could be converted to soda ash by calcination.

Economic Factors

Prices.—The list prices of natural and synthetic soda ash historically were identical until the mid-1970's when higher energy costs and costs to implement the controls imposed by

antipollution legislation caused the synthetic soda ash price to increase compared to that of the natural material. New natural soda ash producers came on-stream in 1976 and 1982 and contributed to slight changes in price-value trends. Changes in the domestic demand pattern also affected average annual values, especially after 1980, when domestic demand declined.

The list prices quoted in trade journals or by producers differ from the annual average values reported to and by the U.S. Bureau of Mines. The values are the combined total revenue of California and Wyoming natural bulk, dense soda ash sold on an f.o.b. plant basis at list-prices, spot-prices, discount, long-term contracts, and for export, divided by the quantity of soda ash sold. This value may or may not correspond to the posted list prices. (*See table 5.*)

Tariffs.—The United States imposes a 1.2% ad valorem tariff on imports of soda ash from countries having most-favored-nation (MFN) status. There is a 8.5% ad valorem tariff on imports from non-MFN sources.

Many nations levy import tariffs or antidumping duties of varying percentages on U.S. soda ash. In western Europe, an antidumping duty of 67.5 European Currency Units (about \$67.13 per ton) had been imposed on U.S. soda ash sold on the continent; however, the duty was rescinded in late 1990. Import tariffs in some other countries in 1991 were as follows: Republic of South Korea, 15%; Taiwan, 12.5%; Thailand, 10%; Indonesia, 5%; Japan, 3.9%; and Malaysia, 2%. Some of these duties will decline over time.

Taxes.—The total effective tax rate on the Wyoming trona industry is about 12.64% and comes from two major taxes. The trona severance tax of 5.5% is a State excise tax on minerals as they are removed from the ground and are applied as a percentage of assessed valuation. The collected taxes are disbursed to the Permanent Wyoming Mineral Trust Fund (2.0%), the General Fund (2.0%), and

the Capital Facilities Revenue Account (1.5%). The property, or ad valorem, tax is about 7.14% of the assessed value of trona produced from the mines. The ad valorem taxes on trona are higher than any other Wyoming minerals, including oil, gas, and coal. Other ad valorem taxes are placed on the assessed value of real property (buildings and equipment) and State sales and use taxes on equipment and facilities.

Royalties.—Soda ash mined on Federal lands is subject to the Mineral Leasing Act of 1920, which provides royalty payments to the United States Government. The Federal royalty is 5% of the quantity or gross value of the output of the product at the point of shipment to market. Each Federal lease also has other costs, such as bonds, acreage rental fees, sodium prospecting permit application fees, and permit bonds. In Wyoming, the soda ash deposit within the Known Sodium Leasing Area is under the jurisdiction of the U.S. Government (administered by the Bureau of Land Management), the State, and the Union Pacific Railroad, which was given alternate 1-square-mile sections north and south of the railway it constructed in the 1860's. Of the almost 915,000 total acres of sodium mineral estate, the Federal ownership is 55.7%, Union Pacific, 38.1%; and the State, 6.2%. Sixteen lessees hold 53 active and inactive Federal leases having a total of 75,783 acres. In order to prevent a possible land monopoly, no lessee may hold more than 15,360 acres of Federal land, but may lease more private or State land. The State royalty rate is tied to the Federal rate of 5%; however, the private royalty rate varies. One-half of all Federal royalties collected by the Minerals Management Service is disbursed back to Wyoming for various State and local programs.

In California, the Federal Government maintains 33 sodium mineral leases having 26,799 acres. The major lessee is North American Chemical Co., which produces soda ash, sodium sulfate, and salt on its sodium leases on Searles Lake.

Depletion Provisions.—The mineral depletion allowance granted to the mining industry through legislation passed by the U.S. Government has been an important inducement for companies willing to accept the risk and high cost of mining development. The concept of depletion allowances for minerals is similar to the depreciation of other assets. Although cost depletion and percentage depletion are two methods used to compute depletion deductions, most companies prefer to use the latter. About 100 mineral categories are entitled to percentage depletion. The rates range between 5% and 22% of the gross income from the mineral property, depending on the mineral and location (foreign or domestic), and are subject to a limitation of 50% of the net income from the property. The significance of percentage depletion is that the deduction is based on the quantity of the first marketable product (soda ash and not trona) and not necessarily on the amount invested. The mineral depletion allowance for soda ash is 14% for U.S. companies mining from domestic or foreign sources.

Operating Factors

Operating factors are different for mining companies than for manufacturing facilities engaged in producing natural soda ash and synthetic soda ash, respectively. The shift in U.S. soda ash production from synthetic to natural has been caused by higher costs attributed to the greater energy and labor requirements of the Solvay process and to environmental regulations. Within the natural soda ash industry, the operating factors vary for producing the commodity from brines and from trona ore.

Environmental Requirements.—U.S. natural soda ash facilities do not have difficult problems disposing of effluents. Residual insoluble material is piped to surface tailing ponds and allowed to settle. Some soda ash in solution that is not economically recoverable from processing is discharged and is converted to sodium decahydrate in the ponds and precipitates on the bottom of ponds to

become an additional source of soda ash if needed. For example, FMC has been dredging some of its sodium decahydrate that has been accumulating since 1950. Some pond water is recirculated into the mines and used as drilling and cutting coolant. Because of changes in environmental legislation in Wyoming, Tenneco Minerals has begun discharging its waste material into abandoned sections of its underground mine, thereby using less surface area on the surface for tailing ponds. The expense of underground discharge is partially offset with the reduction in costs of constructing and maintaining surface tailing ponds.

The alkaline surface ponds, with a pH up to 10.5, have posed some problems for migratory fowl that land on the ponds. The alkaline solutions strip the insulative natural oils from the feathers, thereby increasing the vulnerability of the birds to death from hypothermia. Also, birds have drowned because of the weight of sodium decahydrate that crystallizes on them when the temperature falls below 4° C (40° F). All trona producers have established a rehabilitation program to recover and release contaminated birds and to minimize the mortality and morbidity rate.

Land surrounding trona operations in Wyoming is relatively undeveloped, and the influx of large numbers of workers has caused great strain on the local facilities for housing, schools, shopping, and entertainment. Soda ash companies have provided financial assistance to aid local government in handling any overloads caused by the migration of their employees and families into the community. The companies have given financial aid to employees purchasing homes in the surrounding communities and other fringe benefits such as low-cost transportation to and from work.

Toxicity.—Although soda ash is not considered a highly toxic substance, contact with the eyes may be injurious and prolonged contact with the skin may cause irritation, especially to those who have allergic reactions to alkaline materials. It has also been found to be corrosive to the stomach lining if

ingested. It has an acute oral lethal dose (LD50) of 2.8 grams per kilogram (when tested on a rat) and a primary skin irritation index (PSII) of 2.54 (when tested on a rabbit). Simultaneous exposure to soda ash and lime dusts should be minimized because in the presence of moisture, as from perspiration, the two materials combine to form caustic soda, which is very harmful. Soda ash is not flammable, and the dust is not explosive.

Employment.—According to the Wyoming Office of the State Inspector of Mines, the Wyoming soda ash industry in 1980 employed 3,931 people, of which 1,817 were underground workers, to produce 11.7 million tons (12.9 million short tons) of trona. In 1991, 3,020 people were employed, of which 1,237 underground workers produced 14.6 million tons (16.1 million short tons) of ore. From 1980 through 1991, the underground work force was reduced about 32% while the quantity of trona increased 25%. This represented an 84% increase in the amount of ore mined per worker per year; 6,439 tons in 1980 and 11,803 tons in 1991.

Energy Requirements.—Natural soda ash plants consume considerably less energy per unit of product produced than do synthetic soda ash facilities. As the cost of energy has increased since the 1973 energy crisis, the differential in production costs between natural and synthetic soda ash has become greater. This is one of the major reasons why U.S. natural soda ash has maintained its competitiveness in the world market.

An early U.S. Bureau of Mines energy study using 1973 data indicated that 15.8 million British thermal units (Btu's) was required to produce 1 ton of synthetic soda ash, whereas the energy requirement to produce the same quantity from trona was 7.2 million Btu's. The domestic soda ash industry has reduced its energy requirements significantly since 1973 by replacing gas-fired dryers with steam-tube units and installing mechanical vapor recompression units to replace triple-effect evaporators. The industry has also

converted to coal exclusively or combined with other fuel sources. Plants operated by Tg and Tenneco and the Argus plant operated by North American Chemical Co. use coal only. As a result of these energy saving measures, the Wyoming soda ash industry lowered its energy requirement to a range of 4.5 to 6 million Btu, depending on the individual producer. An estimated one-half of the energy consumed in natural soda ash refining using triple-effect evaporators is for evaporating, one-third is for calcining, and the remainder, for drying.

These energy requirements exclude the amount of energy needed to ship soda ash to foreign markets. Although it has been estimated that it would take about 2.9 million Btu's of additional energy to transport soda ash by rail and by ship to western Europe, nevertheless natural soda ash production requires less energy than the Solvay process or any other synthetic technique.

Transportation.—The western geographic locations of the domestic natural soda ash industry often pose problems because of the great shipping distance to most foreign customers. Even within the United States, the majority of domestic consumption is in the Midwest and east of the Mississippi River. Overland and ocean transportation rates become important factors in the delivered price of soda ash and must be considered seriously in negotiations with foreign consumers who often have alternate supply sources. Bulk freight rates can usually be reduced by shipping in larger volumes, such as in 7,500 ton units.

The railroad is the dominant mode of transportation for the shipment of soda ash. In Wyoming, the Union Pacific Railroad provides the main service to the industry. All bulk soda ash that is railed is carried in covered hopper cars, each handling about 98 tons. Although the railroad companies make their cars available, most soda ash companies have their own sizable fleet.

Beginning in 1985, soda ash was shipped in large quantities by truck. Bonneville Transloaders, Inc. trucked soda ash from Green River to the

Burlington Northern Railroad's line at Shoshoni, WY. Of the almost 8.4 million tons (9.2 million short tons) of soda ash produced in Wyoming, Bonneville trucks about 770,000 tons (850,000 short tons) out of Green River. Other trucking companies have started similar operations with the Southern Pacific (shipping more than 227,000 tons or 250,000 short tons per year) and Denver Rio Grande railroads to compete with Union Pacific.

The railroads have been involved in establishing soda ash bulk loading terminals at ports to handle large volumes of material for export. Kansas City Southern Railroad's terminal at Port Arthur, TX, has a railcar unloading capacity of about 1,000 tons per hour. Material is conveyed to a ship loader spout for transfer to bulk cargo ocean vessels. Port Arthur was the third largest port of the 23 ports that shipped soda ash in 1991, most of which was shipped to South America. The Columbia-Snake customs district in the Pacific Northwest has a bulk loading terminal that transferred the most soda ash, 57%, in 1991.

ANNUAL REVIEW

Issues

Although world soda ash production declined by 2.9% in 1991, domestic production decreased only 1.6%. These declines were a result of the adverse economic conditions in the world that affected virtually every industry sector that consumed soda ash. Despite the decrease in U.S. production, U.S. exports rose 14%, which indicates the preference for the less expensive U.S. product by foreign consumers.

The major issues and events in 1991 that affected the U.S. soda ash industry were some changes in the international activities of some of the world soda ash producers. Botswana brought on-stream its new natural soda ash facility, Solvay et Cie of Belgium reclaimed its old synthetic soda ash plant in Bernburg in eastern Germany, and Imperial Chemical Industries of England sold its synthetic soda ash plants in England and its natural

soda ash operation in Kenya. In addition, plans were announced to close one synthetic soda ash plant in Czechoslovakia and in France and construct one in Saudi Arabia.

The elimination of the antidumping duties in 1990 on U.S. soda ash entering Europe permitted U.S. soda ash exports to that region to rise from 6% of total exports in 1990 to 13% in 1991. Other important issues confronting the growth of U.S. soda ash have been reactions to the political events in Eastern Europe and the reunification of Germany, both areas that have tremendous potential for increased soda ash consumption. The export opportunities are encouraging, pending a favorable resolution to the political and economic turmoil in that area of the world.

Production

Domestic production of natural soda ash from California and Wyoming decreased slightly to 9.005 million tons. About 117,000 tons of soda ash equivalent from soda liquors and mine waters was included in the total and used primarily for neutralizing powerplant process water. The liquors represent a growing market for soda ash producers and provide additional revenue.

At Green River, WY, Tenneco Minerals Co. commissioned its 75,000-ton-per-year liquid caustic soda plant and its 50,000-ton-per-year sodium sulfite facility, both of which use crude trona ore as feedstock. These two commodities take advantage of the same inexpensive mineral feedstock that is used to make refined soda ash. Producing additional value-added products from trona helps provide more revenue for the producing companies.

On May 28, 1991, Tg Soda Ash, Inc., and ATOCHEM North America Inc., both members of Societe Nationale Elf Aquitaine of France, awarded an engineering contract to Ahlstrom Recovery Inc., a global leader in designing and constructing causticizing and lime kiln equipment.² The project to make chemical caustic soda was announced in August 1990. The plant will

have an annual production capacity of 136,000 tons (150,000 short tons), which was higher than originally reported, with startup scheduled for 1992. By yearend, the design capacity of the facility reported was downrated to about 91,000 tons (100,000 short tons). The company will use available sodium carbonate-rich mine water to produce the caustic soda. ATOCHEM has a chloralkali facility in Tacoma, WA, that produces electrolytic caustic soda and coproduct chlorine. Once completed, there will be three Wyoming soda ash plants that have the capacity to produce chemical caustic soda.

In August, Rhone Poulenc of Wyoming awarded a \$10.5 million contract to Jacobs Engineering Group to provide engineering, procurement, and construction services to increase production capacity at its Wyoming soda ash facility. Upgrading improvements will include ore size reduction and screening, material transport, calcining, recrystallization, evaporation, air pollution control, and product bagging and loading. Once implemented, the nameplate capacity of the plant will increase from 1.78 million tons (1.96 million short tons) to 2.0 million tons (2.2 million short tons).³

On December 31, 1991, Rhone Poulenc of Wyoming transferred all of its assets into a new limited partnership in which it became a limited partner. The name of the new Delaware-based limited partnership is Rhone Poulenc of Wyoming, L.P. No changes in personnel or operational procedures occurred in the transaction.

Consumption and Uses

U.S. apparent consumption in 1991 decreased 6% compared with that of the previous year, whereas reported consumption declined 4%. The discrepancy between the two was attributed to disagreement between the sources of export data used to derive consumption statistics. The two sources were the Bureau of the Census, which reports exports upon departure from the U.S. port, and the soda ash producers,

which consider a shipment as exported when their export association (ANSAC) takes charge at California or Wyoming plant sites. Transit times between the plant and port and carryover export inventories contribute to the discrepancy between reported and apparent consumption.

The economic recession in 1991 had a negative effect on the domestic glass industry. Based on reported industry sales, the manufacture of glass products decreased 6%. Glass manufacture represented about 48% of domestic soda ash consumption, with the container sector comprising 61% of this end use; flat, 26%; fiber, 7%; and specialty, 6%. The other end uses include chemicals (primarily sodium bicarbonate, sodium chromates, sodium phosphates, and sodium silicates), 24%; soap and detergents, 13%; distributors, 6%; flue gas desulfurization, 3%; and pulp and paper, water treatment, and miscellaneous, 2% each.

U.S. reported consumption of soda ash decreased in the chemical, soap and detergent, and flue gas desulfurization sectors in 1991. The change in demand was because of the general economic conditions of the major soda ash-consuming markets.

Less soda ash was used in glass containers because of the increased use of recycled cullet. Sales to the flat glass sector declined mainly due to the downturn in the national economy that adversely affected the building construction and automobile industries. The industrial building construction industry consumes about 57% of all flat glass made, whereas the automotive glass sector used 25%. The remainder went to specialty flat glass products. (See table 6.)

The third largest use of soda ash is in detergents. It is used as a builder to emulsify oil stains, reduce the redeposition of dirt during washing and rinsing, provide alkalinity for cleaning, and soften laundry water. In addition, soda ash is a component of sodium tripolyphosphate (STPP), another major builder in detergent formulations, but soda ash consumption has been

decreasing because phosphatic detergents can contribute to the environmental problems of eutrophication. Many regions of the nation have adopted phosphate limitations or bans. These areas represent about 33% of the U.S. population. In response to the environmental issue, detergent manufacturers began reformulating their detergents to make compact and superconcentrated products. These reformulations require sodium silicates and synthetic zeolites, which are made from soda ash. Liquid detergents, which do not contain any soda ash, compete with powdered detergents and command 40% of the household laundry detergent market, up from only 15% in 1978.

Stocks

Yearend stocks of dense soda ash in plant silos, warehouses, terminals, and on teamtracks amounted to 233,941 tons. Producers indicate that a potential supply problem could exist when inventories fall below 180,000 tons. Most consumers of soda ash do not have storage facilities to accommodate large quantities of soda ash and must rely on suppliers to provide the material on a timely basis.

Markets and Prices

Domestic and export sales are essentially the two markets for soda ash. In the domestic market, the large volume buyers of soda ash are primarily the major glass container manufacturers, whose purchases are seasonal (more beverage containers made in second and third quarters for summertime beverage consumption). Soda ash sales to the flat glass sector are usually dependent on the state of the economy because the largest use of flat glass is in automobile manufacture and residential housing and commercial building construction. These two major industrial sectors are especially sensitive to changing economic conditions. If construction starts and automobile sales are up, soda ash sales will proportionally follow.

On August 12, Rhone Poulenc Basic Chemicals raised its off-list price by \$6

per short ton for dense soda ash with a limit of \$98 per ton for its list price. FMC Corp. announced that effective September 1, its off-list price would increase by \$6 per short ton with the list price not to exceed \$98 per ton. Both companies raised their bulk light ash list prices by \$5 per short ton to \$103 per ton. In late August, General Chemical and Tenneco made similar announcements. General's \$6 per short ton price hike would be effective August 26 while Tenneco's would be effective immediately. North American Chemical Co. of California followed the Wyoming producers and raised its off-list price by \$6 effective September 9. The f.o.b. Wyoming prices per short ton are: bulk dense, \$98; bulk "Lite," \$103; 100 pound bags of dense, \$146; 100-pound bags of "Lite," \$151; 50-pound bags of dense, \$156; and 50-pound bags of "Lite," \$161.⁴

Despite the downturn in domestic soda ash consumption, the average annual value for dense natural soda ash, f.o.b. Green River, WY, and Searles Valley, CA, was \$92.79 per ton (\$84.18 per short ton), which was an increase of 1.6% over that of the previous year. The value is not a "price"; it is the value of the combined revenue of California and Wyoming bulk dense soda ash sold on an f.o.b. plant basis at list prices, spot prices, discount, long-term contracts, and for export, divided by the quantity of soda ash sold. (See table 7 and figure 2.)

Foreign Trade

U.S. soda ash exports rebounded in 1991 to reach a record high of 2.7 million tons. U.S. exports to 49 countries, on a regional basis, were as follows: Asia, 40%; South America, 22%; North America, 14%; Europe, 13%; Africa, 5%; Oceania, 3%; and Central America, the Middle East, and the Caribbean, 1% each. (See tables 8, 9, 10, and 11 and figures 3 and 4.)

World Review

Solvay et Cie of Belgium and Imperial Chemical Industries of England (ICI), Europe's two largest synthetic soda ash producers, were fined a total of \$64 million by the European Community Commission for operating as a cartel in the European Currency Unit (ECU) 1 billion European soda ash market. The fine is the largest ever imposed by the Commission. In addition to Solvay and ICI, which were fined ECU 30 million and ECU 17 million, respectively, Chemische Fabrik Kalk of Germany was also fined ECU 1 million. The three companies violated Articles 85 and 86 of the Treaty of Rome that pertain to restrictive practices of competition. According to the Commission, Solvay kept out of United Kingdom and Irish markets while ICI kept out of selling to the European continent. In addition, the two companies operated an illegal rebate scheme that made it unattractive for customers to obtain alternate supply sources.⁵

The European Community Commission eliminated the antidumping duties and price commitments on imported soda ash entering the region from the former East Germany. Products exported to eastern Germany by the U.S.S.R., Bulgaria, Czechoslovakia, Hungary, Poland, Romania, and Yugoslavia on the basis of former bilateral agreements will continue to be exempt from antidumping or customs duties until yearend 1992, provided the goods are consumed in eastern Germany or undergo a transformation that makes them "of EC origin."⁶

Industry Structure.—The developed nations are generally the largest consumers of soda ash. Although the production and consumption quantities vary among the countries, the end-use patterns are basically the same (e.g., glass, chemicals, and detergents are the major sectors). Although the United States is the largest soda ash-producing country in the world, foreign ownership in the U.S. soda ash industry is presently 30% of nameplate capacity.

Eleven countries have the capability to produce more than 1 million tons annually. The major ones include, in descending order, the United States, U.S.S.R., China, the Federal Republic of Germany, India, Japan, France, and Bulgaria. Most of these countries have large populations that require consumer products made with soda ash. The lesser developed nations tend to have greater soda ash demand and higher rates of growth as soda ash-consuming industries are developed. (See table 12.)

Capacity.—World soda ash production capacity is about 35 million tons divided among 36 countries. Approximately 70% of world capacity is synthetic soda ash, 30% natural. The United States represents 28% of world capacity, and 94% of the total natural capacity.

The largest soda ash company in the world, excluding State-owned facilities, is Solvay et Cie of Belgium. It operates nine plants in seven countries and has a combined annual capacity of more than 4.3 million tons. FMC Wyoming Corp. of the United States is the second largest, with 2.59 million tons (2.85 million short tons) of capacity.

Botswana.—The \$504 million natural soda ash project of Soda Ash Botswana (SAB), the venture formed by the Botswana Government and African Explosives and Chemical Industries with its partners, the Anglo American Corp. and De Beers Holdings, commenced production in April 1991. A wellfield containing 40 wells covering 200 square kilometers was developed to supply the newly constructed soda ash refinery. The wells were sunk to depths of about 35 meters. Most of the output from the 300,000-ton-per-year facility was dedicated to markets in the Republic of South Africa. To assist the export market, SAB built a storage facility at Natsalspruit, Republic of South Africa, that will accommodate 40,000 tons of soda ash. Sales to South Africa will be handled by Suachem, a Botswana subsidiary of Chemical Services Ltd. Soda ash sales to Zambia and Zimbabwe will be

administered by SAB's main office at Sua Pan.⁷

Czechoslovakia.—Tonaso, the state agency that owns a synthetic soda ash plant at Nestemice, North Bohemia, announced that it will shut down the 100,000-ton-per-year plant, which was built in 1906. Solvay et Cie was invited to inspect the plant with the idea of purchasing it; however, the cost to retrofit the facility with more modern equipment was not cost effective. The site will continue to serve as a distribution center for Solvay's soda ash entering Czechoslovakia from its Bernburg, Germany, soda ash plant, which is located nearby, and was recently returned to Solvay in 1991. Once Tonaso is privatized in mid-1992, it will set up joint projects with Solvay.⁸

Germany, Federal Republic of.—On September 1, Solvay et Cie of Belgium regained control of its 540,000-ton-per-year synthetic soda ash plant at Bernburg, eastern Germany, which it lost in 1939 when the Nazis took control. About \$114 million will be invested in the next 5 years to modernize the light soda ash plant, and one-half of this investment will be spent to adjacently construct a 300,000-ton-per-year dense soda ash plant. Dense soda ash, which is scarce in central Europe, is preferred by the glass industry. The new plant is expected to be on-stream by 1993 and will serve some of the markets in Czechoslovakia that were disrupted when Solvay announced the closure of the Nestemice facility in 1991. In addition, the Bernburg complex is in the Sachsen-Anhalt region, which is geographically suited to serve markets in eastern Germany and Central Europe. The Bernburg soda ash plant began operation in July 15, 1883.⁹

Saudi Arabia.—Plans were approved for International Chemical Industries and Trading Co. Ltd. to construct a 250,000-ton-per-year synthetic soda ash plant at Al Jubail, near the Persian Gulf coast. One-half of the plant's production was slated for domestic consumption and the

remainder for export to other Middle Eastern countries. The \$240 million facility is scheduled to begin construction by mid-1993 and to be on-stream by 1996 using Akzo Salt and Basic Chemicals International BV ammonia-soda technology.¹⁰

Turkey.—Etibank, the state mining agency, awarded a mining engineering contract to CDF International to investigate the best method to mine the Beypazari trona deposit. Eight companies remain prospective partners with Etibank. They are BHP—Utah, FMC Corp., Rhone Poulenc, Solvay et Cie, and the four Turkish companies Demirexport, Orkimsen, Stfa, and Sise CAM.¹¹

United Kingdom.—Imperial Chemical Industries (ICI) sold the bulk of its world soda ash operations in June to Penrice Ltd. of Australia for \$150 million. Penrice previously bought ICI's 400,000-ton-per-year synthetic soda ash plant in Australia in 1989. The purchase includes all of ICI's soda ash plants in England, which have a combined capacity of 1 million tons, and its natural soda ash plant at Lake Magadi, Kenya, which has an annual production capacity of 300,000 tons. ICI retains its 61% share in the soda ash operation in Pakistan. That plant has a capacity of about 100,000 tons per year. Penrice's acquisitions were renamed Brunner Mond Holdings Ltd., which was the original name of the company before ICI was formed in 1926. Under this parent corporation, the English operation will be known as Brunner Mond and Co., the Kenyan operation as Magadi Soda, and the Australian operated as Penrice Soda Products.¹²

OUTLOOK

The world soda ash industry is restructuring itself to become more competitive in response to the growing international environmental movement. Older, less profitable synthetic soda ash plants will be evaluated for their effectiveness and closed if necessary. The closure of the soda ash plants in Czechoslovakia and France in 1991

emphasizes this. Foreign companies will continue to consider investing in natural soda ash ventures in Wyoming and California in order to guarantee long-term and inexpensive supplies of soda ash.

Exports

The outlook for U.S. soda ash is excellent. The two largest exporting organizations in the world are Solvay and the American Natural Soda Ash Corp. (ANSAC). Although ANSAC is prohibited from exporting to the European Community nations, the six individual U.S. soda ash producers will strive to increase exports to that region. Export opportunities to the Middle East and South America are very favorable. The changes in the political situation in the U.S.S.R. and eastern Europe may also lead to more U.S. exports to meet the growing demand for consumer products in those areas. The limiting factor, however, may be the lack of available hard currency and the internal manufacturing capabilities of the industries that use soda ash.

Glass

Domestic consumption of soda ash in the glass container sector is declining because of (1) the increasing use of cullet; (2) the national interest in recycling; and (3) the continuing competition with polyethylene terephthalate (PET) plastic containers.

Glass container shipments were less in 1991 than those in previous years. The public's perception that glass is completely recyclable compared to plastics will raise the quantity of cullet now being consumed. Aside from the problems with plastics' recyclability, the public also is concerned about the dioxin emissions from incineration of polyvinyl chloride (PVC) bottles. Flat glass consumption was also down because of adverse economic conditions affecting housing starts and automobile sales.

Municipal landfills are a growing national problem. Glass reportedly accounts for 8.4% of disposable household waste. The U.S.

Environmental Protection Agency has a goal of reducing the Nation's waste by 25% by 1992. It is probable that new taxes will be placed on items manufactured at the source of production to encourage greater use of recycled products. Rebates would be given for every ton of recycled material utilized.

Chemicals

The global chloralkali supply and demand situation in 1991 was not a major problem as was forecast previously. Although a few chloralkali plants shut down during the year, they were basically the unprofitable ones. Chemical caustic soda produced by the lime-soda process will satisfy part of the projected caustic soda shortages. A potential 545,000 tons (600,000 short tons) of caustic soda could be made available from Dow Chemical, pending its decision to produce propylene oxide by a different alternative method. By yearend 1991, the domestic chlorine market rebounded and caustic soda became available at less expensive prices.

Soap and Detergents

About 10 million tons of laundry detergents is consumed annually in the world. Most detergents are composed of many active and inert chemical ingredients. Household liquid detergents and phosphate-free detergents are considered environmentally safe products. More soda ash has been added as a phosphate-replacement builder in various detergent formulations in order to meet regional phosphate discharge requirements.

The environmental movement in Europe has also prompted foreign detergent manufacturers to consider changing formulations to reduce phosphate content. In West Germany, consumption of phosphates in detergents dropped from 276,000 tons in 1975 to 80,000 tons in 1987. The quantity of packaging waste discarded to landfills prompted detergent manufacturers to test-market compact and superconcentrated products in different regions. Whatever amount of soda ash lost due to

reformulation could be partially offset from the use of soda ash in synthetic zeolites and sodium silicates in the new formulations.

Consumer preferences also may determine the preferred detergent and format (i.e., liquid versus powdered, unit dose packets versus bulk). Depending on the choice, the growth of future soda ash sales is optimistic.

Pulp and Paper

Although the U.S. pulp industry is growing at about 2.75% per year, changes are taking place to alter the pulpmaking and papermaking processes. Pulp mills are striving to address the environmental issues regarding dioxins and furans, improve productivity, reduce costs, and improve paper quality. One solution is alkaline paper-sizing, which produces alkaline-based paper rather than acid-based. The conversion is not being implemented as fast as the environmental issue is mounting. Other alternatives include substituting certain pulping chemicals.

Dioxins, created from chlorine molecules introduced in the paper bleaching process, have been detected in bleached paper products as reported in a study of the 104 kraft-pulp mills in the United States. To avert the public's reaction to the issue, the industry began investigating substituting chlorine-base chemicals for nonchlorine pulping and bleaching agents, such as oxygen and hydrogen peroxide. About 1.8 million tons of chlorine is used in pulp bleaching annually. Industry sources estimate a 25% to 30% reduction in chlorine consumption by 1995. If this forecast is accurate, coproduct caustic soda, which is used to delignify wood pulp, could be in short supply. This situation could result in additional quantities of soda ash being used instead of caustic soda, although it would take 1.3 tons of soda ash to have the same chemical effect of 1.0 ton of caustic soda. FMC Wyoming Corp., Tenneco Minerals Co., and Tg Soda Ash, Inc. have made announcements to produce caustic soda from their Wyoming soda ash operations. Although the

majority of the output is for captive needs, the opportunity will demonstrate the economic feasibility of producing caustic soda from nonsalt feedstocks. Soda ash consumption in the pulp and paper sector could increase during the next few years depending on the strength of chlorine demand, which is influenced by the strength of polyvinyl chloride sales.

Flue Gas Desulfurization

The Clean Air Act, as amended by Public Law 101-549, will require the Nation's powerplants to reduce emissions of sulfur and nitrogen compounds produced from burning fossil fuels. Although most high-sulfur coal is used in eastern powerplants where inexpensive calcium-base compounds are located, sodium-base sulfur dioxide removal agents, such as trona and nahcolite, have opportunities for commercial development in the west.

In 1991, about 171,000 tons of soda ash was used for reducing stackgas emissions in the West and Midwest. Transportation costs will reduce the competitiveness of sodium minerals in the East in the future; however, the concern regarding water quality and quantity will be major issues in the Western United States in the 1990's. Several wet-scrubbing utility plants, which use tremendous amounts of water, are evaluating the economics of replacing traditional wet-scrubbing systems using lime with dry-injection technologies using calcium- and sodium-base agents. The addition of some sodium minerals removes additional sulfur and a substantial amount of the nitrogen materials. Eastern powerplants will probably use low-sulfur coal rather than use trona or nahcolite resources found in the West. As Western powerplants retrofit older facilities with dry-injection scrubbing equipment to conserve water, demand for soda ash will increase.

Although the outlook for the U.S. soda ash industry is very good, the structure of the industry continues to change as foreign participation increases. The United States will remain an

important supply source of inexpensive natural soda ash for international consumption. However, a growing percentage will be shipped by the foreign partners of the U.S. resource—primarily Australia, France, Japan, and the Republic of Korea. More shares of the U.S. soda ash industry are available for joint venture at the present time.

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³Chemical Week Chlor-Alkali Marketwire. Soda Ash. Aug. 7, 1991, p. 3.

⁴Industrial Minerals. *World of Minerals*. As Soda Ash Prices Increase. No. 289, Oct. 1991, p. 19.

⁵Chemical Week Chlor-Alkali Marketwire. Soda Ash. Jan. 9, 1991, pp. 3-4.

⁶Industrial Minerals. *World of Minerals*. Botswana. No. 288, Sept. 1991, p. 17.

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¹⁰———. *ICIT Gets Approval for Soda Ash Plant at Al Jubail*. V. 57, No. 1504, Jan. 27, 1992, p. 38.

¹¹Chemical Week. *Solvay Targets Turkish Soda Ash Mining Contract*. V. 149, No. 9, p. 15.

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TABLE 1
SALIENT SODA ASH STATISTICS

(Thousand metric tons and thousand dollars)

	1987	1988	1989	1990	1991
United States:					
Production ¹	8,066	8,738	8,995	9,156	9,005
Value ¹	\$593,685	\$644,973	\$764,146	\$836,188	\$835,577
Production, Wyoming trona	12,582	13,713	14,774	14,665	14,674
Exports ²	2,018	2,238	2,648	2,392	2,734
Value ²	\$253,200	\$286,945	\$365,469	\$346,693	\$409,088
Imports for consumption	136	121	129	146	134
Value	\$18,334	\$15,999	\$17,396	\$20,495	\$21,299
Stocks, December 31: Producers ³	235	261	221	287	234
Consumption:					
Apparent	6,216	6,595	6,516	6,844	6,458
Reported	6,100	6,494	6,469	6,527	6,278
World: Production	30,203	31,261	32,030	32,273	31,344

¹Estimated. ²Revised.

¹Includes natural and synthetic. Natural only, and soda liquors and mine water converted to soda ash equivalent in 1987 and thereafter; 63,469 tons in 1987, 73,365 tons in 1988, 95,027 tons in 1989, 111,894 tons in 1990, and 117,289 tons in 1991.

²Export data for 1986-88 were adjusted by the U.S. Bureau of Mines to reconcile data discrepancies among the Bureau of the Census, the American Natural Soda Ash Corp., and Statistics Canada.

TABLE 2
U.S. PRODUCERS OF SODA ASH IN 1991

Company	Plant nameplate capacity (million tons)		Plant location	Source of sodium carbonate
	Metric tons	Short tons		
FMC Wyoming Corp.	2.59	2.85	Green River, WY	Underground trona.
General Chemical (Soda Ash) Partners ¹	2.09	2.30	do.	Do.
North American Chemical Co. ²	1.18	1.30	Trona, CA	Dry lake brine.
Rhone Poulenc of Wyoming, L.P. ³	1.78	1.96	Green River, WY	Underground trona.
Tenneco Minerals Co. ⁴	1.13	1.25	do.	Do.
Tg Soda Ash Inc. ⁵	1.18	1.30	Granger, WY	Do.
Total	9.95	10.96		

¹A joint venture between General Chemical Corp. (51%) and Australian Consolidated Industries International (49%).

²Acquired Nov. 30, 1990, from Kerr-McGee Chemical Corp., with Oriental Chemical Industries of Korea as partner (27%).

³Joint venture between Rhone-Poulenc Basic Chemicals Co. of France (51%) and Union Pacific Resources Co. (49%).

⁴Formed a joint venture with Asahi Glass Co. of Japan in Feb. 1990. The partnership provides Asahi with 20% of the full nameplate capacity of the operation when the 600,000 tons expansion is completed in late 1992.

⁵Owned by Texasgulf Inc., subsidiary of Societe Nationale Elf Aquitaine of France (100%).

TABLE 3
SODA ASH SUPPLY-DEMAND RELATIONSHIPS¹

(Thousand metric tons)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
WORLD PRODUCTION											
United States	7,513	7,093	7,681	7,721	7,721	7,655	8,066	8,738	8,995	9,156	9,005
Rest of world	20,501	19,714	20,210	21,513	20,514	21,705	22,137	22,523	23,035	23,117	22,339
Total	28,014	26,807	27,891	29,234	28,235	29,360	30,203	31,261	32,030	32,273	31,344
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
U.S. production capacity	9,398	10,124	10,124	10,124	10,124	9,580	9,580	9,512	9,580	9,950	9,950
Wyoming trona ore production	11,301	9,826	10,442	10,618	10,726	12,008	12,582	13,713	14,774	14,665	14,674
Domestic sources	7,513	7,093	7,681	7,721	7,721	7,655	8,066	8,738	8,995	9,156	9,005
Imports	11	16	18	15	51	96	136	121	129	146	134
Industry stocks, January 1 ²	121	239	294	279	292	355	267	235	261	221	287
Total U.S. supply	7,645	7,348	7,993	8,015	8,064	8,106	8,469	9,094	9,385	9,523	9,426
Distribution of U.S. supply:											
Industry stocks, December 31 ²	239	294	279	292	355	267	235	261	221	287	234
Exports	953	1,006	1,484	1,495	1,584	1,859	2,017	2,238	2,648	2,392	2,734
Industrial demand ³	6,453	6,048	6,230	6,228	6,125	5,980	6,217	6,595	6,516	6,844	6,458
U.S. DEMAND PATTERN⁴											
Glass (total):	3,357	3,176	3,130	3,085	3,084	3,152	3,343	3,390	3,294	3,177	2,997
Container	2,383	2,268	2,177	2,087	1,996	1,951	2,107	2,128	1,961	1,909	1,823
Flat	504	454	522	544	635	680	821	852	907	851	767
Fiber	236	200	209	227	249	272	249	246	241	228	206
Other	234	254	222	227	204	249	166	164	185	189	201
Chemicals	1,288	1,179	1,270	1,406	1,361	1,179	1,238	1,445	1,412	1,573	1,510
Soaps and detergents	454	454	562	544	544	590	684	718	781	835	796
Pulp and paper	191	249	181	227	318	181	63	111	114	132	147
Water treatment	227	209	209	272	272	227	72	110	92	91	106
Flue gas desulfurization	NA	NA	NA	272	159	181	183	200	208	207	171
Distributors	NA	NA	NA	NA	NA	NA	349	373	380	376	403
Other ⁵	936	781	878	422	387	470	168	148	188	136	148
Total U.S. consumption	6,453	6,048	6,230	6,228	6,125	5,980	6,100	6,495	6,469	6,527	6,278
Undistributed ⁶	—	—	—	—	—	—	117	100	47	317	180
Total U.S. primary demand	6,453	6,048	6,230	6,228	6,125	5,980	6,217	6,595	6,516	6,844	6,458
VALUES⁷											
Average annual value:											
Dollars per short ton	\$91.19	\$88.35	\$76.95	\$67.00	\$67.82	\$65.29	\$66.78	\$66.96	\$77.07	\$82.85	\$84.18
Dollars per metric ton	\$100.52	\$97.39	\$84.82	\$73.85	\$74.76	\$71.97	\$73.61	\$73.81	\$84.96	\$91.33	\$92.79

¹Estimated. ²Revised. NA Not available; included in "Other."

³Natural and synthetic except where noted.

⁴Natural soda ash only for 1980, and 1987 and thereafter; natural and synthetic from yearend 1981-86.

⁵Also known as apparent consumption (production plus imports minus exports plus or minus stock changes) and is equal to "Total U.S. primary demand."

⁶Estimated consumption for 1980-86 was based on industry sources; reported consumption 1987 and thereafter were from quantitative and qualitative quarterly surveys of producers' sales. Other end-use categories were incorporated in the survey.

⁷Includes soda ash used in petroleum and metal refining, leather tanning, enamels, etc. Also includes data in categories indicated by "NA."

⁸Because end-use data prior to 1987 were estimated, industrial demand and U.S. primary demand calculations (both based on production, trade, and inventory data) were assumed to be equal to total U.S. consumption. Beginning with 1987, reported consumption data by end use often disagreed with derived apparent consumption calculations that necessitated, including an "Undistributed" category to account for the discrepancies. These discrepancies are because of the fluctuating balance of inventory in transit from plants to domestic or export destinations.

⁹Values are the combined total revenue of California and Wyoming natural, bulk, dense soda ash sold on an f.o.b. plant basis, at list prices, spot prices, discount, long-term contracts, and for export, divided by the quantity of soda ash sold. This value may or not be synonymous with the posted list prices of the commodity.

Source: U.S. Bureau of Mines.

TABLE 4
WORLD NATURAL SODA ASH RESERVES
AND RESERVE BASE

(Million tons)

	Reserves		Reserve base ¹	
	Short tons	Metric tons	Short tons	Metric tons
North America:				
United States:				
California:				
Owens Lake	50	45	55	50
Searles Lake	850	770	1,345	1,220
Colorado ^{2,3}	2,600	2,359	4,300	3,900
Wyoming ²	22,000	19,958	37,000	33,566
Total ⁴	25,500	23,130	42,700	38,736
Mexico	200	180	500	454
Total	25,700	23,310	43,200	39,190
Europe:				
Turkey	216	196	260	235
U.S.S.R.	7	6	NA	NA
Total ⁴	223	200	260	235
Africa:				
Botswana	400	363	NA	NA
Chad	8	7	NA	NA
Kenya ⁵	56	51	NA	NA
Tanzania	72	65	NA	NA
Uganda	18	16	NA	NA
Total ⁴	554	500	NA	NA
Asia: China:				
Inner Mongolia	110	100	110	100
Tongbai, Henan	132	120	132	120
Total	242	220	242	220
World total ⁴	26,700	24,200	43,700	39,644

NA Not available.

¹The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).

²Represents only the quantity recoverable based on an average rate of 60% extraction efficiency from room-and-pillar, longwall, and shortwall methods of underground mining. This extraction rate does not apply to brines or surface evaporite lake beds. Solution mining of trona and nahcolite is estimated to have a 30% extraction efficiency rate.

³The sodium carbonate content of nahcolite reserves and reserve base are 0.8 billion short tons and 1.26 billion short tons, respectively. The sodium carbonate content of dawsonite reserves and reserve base are 1.82 billion short tons, and 3.0 billion short tons, respectively.

⁴Data may not add to totals shown because of independent rounding.

⁵Annual leaching of volcanic rocks replenishes the resources at Lake Magadi.

NOTE.—There are at least 62 identified natural sodium carbonate deposits in the world, some of which have been quantified. The countries and number of deposits include Australia (1), Bolivia (2), Botswana (1), Brazil (1), Canada (3), Chad (9), China (9), Egypt (1), Ethiopia (1), India (2), Kenya (3), Mexico (1), Namibia (1), Niger (1), Pakistan (1), the Republic of South Africa (1), Tanzania (5), Turkey (1), Uganda (1), the U.S.S.R. (4), the United States (20), and Venezuela (1).

TABLE 5
TIME-VALUE RELATIONSHIPS
FOR SODA ASH

Year	Average annual value, dollars per ton			
	Natural soda ash			
	Actual value ¹		Based on constant 1991 dollars ²	
	Per short ton	Per metric ton	Per short ton	Per metric ton
1971	21.21	23.38	67.07	73.93
1972	22.28	24.56	67.18	74.05
1973	25.36	27.95	71.84	79.19
1974	33.87	37.34	88.26	97.29
1975	42.20	46.52	100.35	110.62
1976	49.70	54.78	111.18	122.55
1977	54.19	59.73	113.42	125.02
1978	54.51	60.09	105.77	116.59
1979	64.55	71.15	115.30	127.10
1980	89.85	99.04	146.62	161.62
1981	91.19	100.52	135.22	149.05
1982	88.35	97.39	123.35	135.97
1983	76.95	84.82	103.25	113.81
1984	67.00	73.85	86.14	94.95
1985	67.82	74.76	84.06	92.66
1986	65.29	71.97	78.83	86.90
1987	66.78	73.61	78.13	86.12
1988	66.96	73.81	75.40	83.11
1989	77.07	84.96	83.18	91.69
1990	82.85	91.33	85.86	94.64
1991	84.18	92.79	84.18	92.79

¹Values are the combined total revenue of California and Wyoming natural soda ash sold at list prices, spot prices, discount, long-term contracts, and for export, divided by the quantity of soda ash sold on a bulk, f.o.b. basis. The average annual value may not necessarily correspond to posted list prices for soda ash.

²From final 1991 implicit price deflators for gross domestic product and not gross national product, which was used previously. In addition, the base year is 1987 and not 1982.

TABLE 6
REPORTED CONSUMPTION OF SODA ASH IN THE UNITED STATES,
BY END USE

(Metric tons)

SIC code	End use	1987	1988	1989	1990	1991
32	Glass:					
3221	Container	2,106,662	2,128,250	1,961,039	1,908,983	1,822,631
3211	Flat	820,976	851,853	907,333	850,687	767,381
3296	Fiber	249,358	246,273	240,799	227,770	205,888
3229	Other	165,793	163,560	185,083	189,452	201,059
	Total	3,342,789	3,389,936	3,294,254	3,176,892	2,996,959
281	Chemicals	1,237,588	1,445,211	1,412,180	1,572,890	1,509,840
284	Soaps and detergents	684,374	717,894	780,634	834,690	796,305
26	Pulp and paper	63,001	110,996	113,962	131,973	146,674
2899	Water treatment ¹	71,568	109,865	92,268	91,056	106,196
	Flue gas desulfurization	182,899	199,630	208,296	207,067	170,952
	Distributors	349,042	373,439	380,021	375,803	403,286
	Other	169,097	147,456	187,073	136,323	147,289
	Imports ²	136,171	120,609	128,790	145,533	134,312
	Total domestic reported consumption ³	6,100,358	6,494,427	6,468,688	6,526,694	6,277,502
	Export ⁴	2,124,240	2,662,472	⁵ 2,644,61	2,588,477	2,797,145
	Total industry sales ⁶	⁷ 8,224,598	9,156,899	⁸ 9,113,306	9,115,171	9,074,650
	Total production	8,065,559	8,738,042	8,994,717	9,156,036	9,004,790

¹Includes soda ash equivalent from soda liquors, purge liquors, and mine water sold to powerplants for water treatment: 63,469 tons in 1987, 73,365 tons in 1988, 95,027 tons in 1989, and 111,894 tons in 1990.

²Data are from the Bureau of the Census and may vary from the quantity reported by the producer and or importer. Actual imports are proprietary data but have been distributed into appropriate end-use categories and included in "Total domestic reported consumption."

³Reported consumption data do not agree with apparent consumption data shown in tables 1 and 3 because of dissimilar sources of export data. The data vary because of different reporting periods, overland transit times between plant and port, and carryover export inventory.

⁴As reported by producers. Includes Canada. Data may not necessarily agree with that reported by the Bureau of the Census for the same periods.

⁵Revised from monthly Mineral Industry Surveys data because of 181 metric tons (200 short tons) of misreported export data in first quarter 1989.

⁶Represents soda ash from domestic origin (production and inventory changes) and imports, and for exports.

⁷In monthly Minerals Industry Surveys reports, "Total Industry Sales" for 1987 were erroneously reported as 8,088,423 metric tons (8,915,951 short tons). The misreported figure deducted imports, which already had been included in specific end uses under "Total domestic reported consumption."

⁸An extra 23,548 metric tons (25,957 short tons) of coproducer sales is included in total, but specific end-use breakout is unknown.

TABLE 7
SODA ASH YEAREND PRICES

	1990	1991
Sodium carbonate (soda ash):		
Dense, 58%, Na ₂ O 100-pounds:		
Paper bags, carlot, works, f.o.b.	short ton	\$146.00 \$146.00
Bulk, carlot, same basis tons	do.	98.00 98.00
Light 58%, 100-pounds:		
Paper bags, carlot, same basis	do.	150.00 150.00
Bulk, carlot, same basis tons	do.	123.00 123.00

Sources: Chemical Marketing Reporter. Current Prices of Chemicals and Related Materials. v. 238, No. 27, Dec. 31, 1990, p. 31; and V. 240, No. 27, Dec. 31, 1991, p. 31.

TABLE 8
U.S. EXPORTS OF SODA ASH

(Thousand metric tons and thousand dollars)

Year	Disodium carbonate ¹	
	Quantity	Value ²
1987 ³	2,018	253,200
1988 ³	2,238	286,945
1989	2,648	365,469
1990	2,392	346,693
1991	2,734	409,088

¹Beginning in 1989, export data were reclassified under the Harmonized Commodity Description and Coding System (HS Code No. 2836200000). Prior years were classified under Schedule B No. 4208400.

²F.a.s. value at U.S. ports.

³Adjusted by the U.S. Bureau of Mines to account for discrepancies in data.

Source: Bureau of the Census, as adjusted by the U.S. Bureau of Mines.

TABLE 9
REGIONAL DISTRIBUTION OF U.S. SODA ASH EXPORTS, BY CUSTOMS DISTRICTS, IN 1991

(Metric tons)

Customs districts	North America	Central America	South America	Caribbean	Europe	Middle East	Africa	Asia	Oceania	Total	Percent of total
Atlantic:											
Charleston, SC	—	—	—	56	8	—	—	—	—	64	—
Miami, FL	—	58	76	283	—	—	—	—	—	417	—
New York, NY	—	—	178	18	75	—	—	—	—	271	—
Norfolk, VA	—	—	—	—	—	12	—	—	—	12	—
Philadelphia, PA	—	—	4	—	20	—	—	—	—	24	—
Tampa, FL	—	54	—	—	—	—	—	—	—	54	—
Gulf:											
Houston-Galveston, TX	—	—	5,193	38	63,505	—	19	—	—	68,755	3
New Orleans, LA	—	104	105	—	—	—	18	—	—	227	—
Port Arthur, TX	—	1,988	228,513	14,687	—	21,812	—	—	—	267,000	10
Pacific:											
Columbia-Snake	—	3,951	208,169	—	194,466	—	68,162	1,004,290	76,610	1,555,648	57
Los Angeles, CA	—	17,635	171,379	—	83,478	12,082	67,169	100,945	—	452,688	17
San Diego, CA	3,274	—	—	—	—	—	—	—	—	3,274	—
San Francisco, CA	—	—	—	—	—	—	—	18	—	18	—
Seattle, WA	2,835	—	—	—	—	—	—	120	—	2,955	—
North Central:											
Chicago, IL	89	—	—	—	2	—	—	—	—	91	—
Cleveland, OH	89	—	—	—	—	—	—	—	—	89	—
Detroit, MI	92,295	—	—	—	360	—	—	—	—	92,655	3
Duluth, MN	94	—	—	—	—	—	—	—	—	94	—
Great Falls, MT	32,167	—	—	—	—	—	—	—	—	32,167	1
Pembina, ND	10,260	—	—	—	—	—	—	—	—	10,260	—
Northeast:											
Buffalo, NY	633	—	—	—	—	—	—	—	—	633	—
Ogdensburg, NY	213	—	—	—	—	—	—	—	—	213	—
St. Albans, VT	20	—	—	—	—	—	—	—	—	20	—
Southwest:											
El Paso, TX	635	—	—	—	—	—	—	—	—	635	—
Laredo, TX	232,651	—	—	—	—	—	—	—	—	232,651	9
Nogales, AZ	397	—	—	—	—	—	—	—	—	397	—
Other:											
San Juan, PR	—	—	—	20	—	—	—	—	—	20	—
Mail shipments ¹	2,891	—	—	—	—	—	—	—	—	2,891	—
Unknown:	9,870	—	—	—	—	—	—	—	—	9,870	—
Total²	388,413	23,790	613,617	15,102	341,914	33,906	135,368	1,105,373	76,610	2,734,090	100
Percent of total²	14	1	22	1	13	1	5	40	3	100	—

¹Shipments individually valued under \$251 for imports and under \$501 for exports.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 10
U.S. EXPORTS OF SODA ASH, BY COUNTRY

(Metric tons)

Country	1987	1988	1989	1990	1991
Algeria	—	—	(¹)	4,057	18
Angola	—	—	—	(¹)	—
Argentina	51,621	32,671	86,735	74,259	123,894
Aruba	—	3	—	—	—
Australia	36,154	62,126	66,596	72,737	59,334
Bahamas	58	11	—	5	—
Barbados	9	—	—	—	—
Belgium	—	² 11,119	—	—	44,400
Belize	—	—	34	8	—
Bermuda	34	8	33	1,075	18
Bolivia	2,216	2,474	1,449	554	900
Brazil	143,779	136,345	220,381	101,873	204,390
Bulgaria	—	(³)	—	—	—
Canada	⁴ 150,545	⁴ 180,195	⁴ 252,741	151,480	151,455
Cayman Islands	5	—	—	—	—
Chile	29,534	47,382	72,680	39,425	58,901
China	282,759	⁵ 331,597	317,086	56,159	58,092
Colombia	13,804	34,608	26,252	21,910	10,299
Costa Rica	5,871	2,009	5,577	8,479	7,935
Dominican Republic	5,858	2,074	5,219	2,722	2,724
Ecuador	8,732	7,649	11,281	10,634	4,475
El Salvador	—	1,730	3,146	—	2,986
France	—	11,125	4,874	11,474	28,131
Gabon	—	—	—	1	—
Germany, Federal Republic of	21	204	45	64	376
Ghana	—	—	—	—	—
Guatemala	4,970	14,801	4,951	—	8,810
Guyana	—	—	—	8	5
Haiti	—	(¹)	—	41	61
Honduras	15	⁶ 39	14	7	—
Hong Kong	⁷ 172,294	⁷ 116,779	⁷ 189,571	40,734	2,898
Hungary	—	—	—	9,916	—
India	—	—	24	—	—
Indonesia	85,961	110,102	179,502	173,920	189,676
Iran	—	—	—	43,248	—
Ireland	—	—	—	(¹)	—
Israel	—	5,860	—	9,757	10,450
Italy	—	3	—	—	—
Jamaica	4,055	5,983	3,998	6,059	3,561
Japan	224,088	247,175	289,781	337,207	273,729
Jordan	—	1	—	—	—
Kenya	140	7	—	—	—
Korea, Republic of	35,283	130,495	131,458	190,521	231,920

See footnotes at end of table.

TABLE 10—CONTINUED
U.S. EXPORTS OF SODA ASH, BY COUNTRY

(Metric tons)

Country	1987	1988	1989	1990	1991
Kuwait	—	—	—	20	—
Leeward and Windward Islands	—	—	—	—	—
Malaysia	27,713	27,790	21,324	55,844	37,709
Mexico	129,251	77,996	141,731	191,820	236,957
Morocco	—	—	—	600	—
Netherlands	9,128	328	3	20,028	63,505
Netherlands Antilles	—	5	9	—	—
New Zealand	32,901	21,098	23,000	24,397	17,276
Panama	3,618	1,891	1,526	2,181	4,059
Peru	34,283	17,714	15,030	11,181	15,997
Philippines	48,636	34,975	90,324	86,095	71,245
Poland	—	—	—	—	32
Qatar	—	10	—	—	—
St. Lucia	—	—	—	5	—
Saudi Arabia	—	5	(¹)	—	12
Senegal	—	—	17	—	—
Singapore	—	*6,001	4,946	12,987	10,056
South Africa, Republic of	134,121	165,361	186,952	170,370	135,331
Spain	—	2	—	9	71,568
Sudan	—	—	7	—	—
Suriname	—	23	152	—	—
Sweden	32,722	38,901	25,086	20,521	25,421
Switzerland	—	—	—	447	—
Taiwan	47,895	99,134	69,793	112,449	118,571
Thailand	27,099	71,051	69,167	103,635	111,476
Trinidad and Tobago	8,137	5,684	8,321	5,624	8,737
Turkey	—	—	—	58,530	—
United Arab Emirates	1	—	—	—	—
United Kingdom	34,167	34,461	27,422	34,179	108,481
Uruguay	—	—	—	2,990	1,688
U.S.S.R.	—	(²)	—	—	—
Venezuela	189,921	140,973	90,183	109,766	193,067
Yugoslavia	—	—	—	—	23,444
Total ¹⁰	2,017,400	2,237,981	2,648,439	2,391,996	2,734,090

¹Less than 1/2 unit.

²Adjusted using PIERS data to include 12,257 tons exported in Mar. and Sept. through Los Angeles, CA, customs district.

³In July, 33,069 tons was shipped to China, but credited to Bulgaria, by United States to fulfill Bulgarian export commitment. Data included with China.

⁴Data representing imports from the United States through Dec. 1987 as reported by Statistics Canada, International Trade Div. The Bureau of Census export statistics indicated only 140,102 tons in 1987 and 123,254 tons in 1988.

⁵Includes 33,069 tons shipped by United States but credited to Bulgaria.

⁶Adjusted using PIERS data to include 43 tons in July through Tampa, FL, custom district.

⁷The majority was bagged and transhipped to China.

⁸Adjusted to include 4,410 tons shipped in September and December.

⁹Erroneous notation of shipment of 1,193 tons (\$190,800), to U.S.S.R. through Houston customs district in May. The error is not included in total.

¹⁰Data may not add to totals shown because of independent rounding.

Sources: Bureau of the Census and Statistics Canada, as adjusted by the U.S. Bureau of Mines.

TABLE 11
U.S. IMPORTS FOR
CONSUMPTION OF SODA ASH

Year	Disodium carbonate ¹	
	Quantity (metric tons)	Value ² (thousands)
1987 ³	136,171	\$18,334
1988 ³	120,609	15,999
1989	128,790	17,396
1990	145,534	20,495
1991	134,312	21,299

¹Beginning in 1989, import data were reclassified under the Harmonized Commodity Description and Coding System (HS Code No. 2836200000). Prior years were classified under the Tariff Schedule of the United States, Annotated, TSUSA No. 4208400 (calined) and No. 4208600 (hydrated and sesquicarbonate).

²C.i.f. value at U.S. ports.

³Also contains sodium carbonate, hydrated and sesquicarbonate.

Source: Bureau of the Census.

TABLE 12
SODA ASH: WORLD PRODUCTION, BY COUNTRY¹
(Thousand metric tons)

Country	1987	1988	1989	1990	1991 ^a
Albania	31	22	27	27	25
Australia ^a	300	300	300	300	300
Austria ^a	150	145	150	150	150
Belgium	448	379	380	380	375
Botswana	—	—	—	—	60
Brazil	170	184	197	200	200
Bulgaria	1,070	1,100	1,100	1,046	1,000
Canada ^a	325	325	325	315	300
China	2,363	2,609	3,042	3,746	3,800
Colombia	117	114	114	121	120
Czechoslovakia	103	112	110	104	100
Denmark ²	* (°)	(°)	* (°)	(°)	(°)
Egypt ^a	45	48	47	52	52
France ^a	1,270	1,270	1,300	1,200	1,100
Germany:					
Eastern states	893	914	900	850	NA
Western states	1,448	1,404	1,443	1,436	NA
Total	2,341	2,318	2,343	2,286	2,000
India	970	1,098	1,344	1,400	1,500
Italy ^a	612	612	615	610	600
Japan	1,098	1,083	1,105	1,135	1,140
Kenya ³	229	220	241	244	245
Korea, Republic of ^a	289	280	280	280	300
Mexico ⁶	417	421	456	448	450
Netherlands ^a	380	400	400	400	390
Pakistan	133	134	135	135	137
Poland	930	956	1,005	1,000	1,000
Portugal ^a	160	155	150	150	150
Romania ^a	860	860	800	800	700
Spain ^a	550	560	560	550	500
Switzerland ^a	23	—	—	—	—
Taiwan	127	127	116	120	120
Turkey ^a	376	379	381	385	385
U.S.S.R. ⁷	5,049	5,097	4,809	4,359	4,000
United Kingdom ^a	1,000	1,000	1,000	1,000	1,000
United States ⁵	8,066	8,738	8,995	9,156	9,005
Yugoslavia	202	214	204	173	140
Total	30,203	31,261	32,030	32,273	31,344

^aEstimated. ^rRevised. NA Not available.

¹Table includes data available through Apr. 20, 1992. Synthetic unless otherwise specified.

²Production for sale only; excludes output consumed by producers.

³Less than 1/2 unit.

⁴Reported figure.

⁵Natural only.

⁶Includes natural and synthetic. Estimated production of natural soda ash, in thousand metric tons, was as follows: 1987-180; 1988-175; 1989-190; 1990-190; and 1991-190.

⁷Excludes potash for 1987.

FIGURE 1
U.S. SODA ASH TRENDS

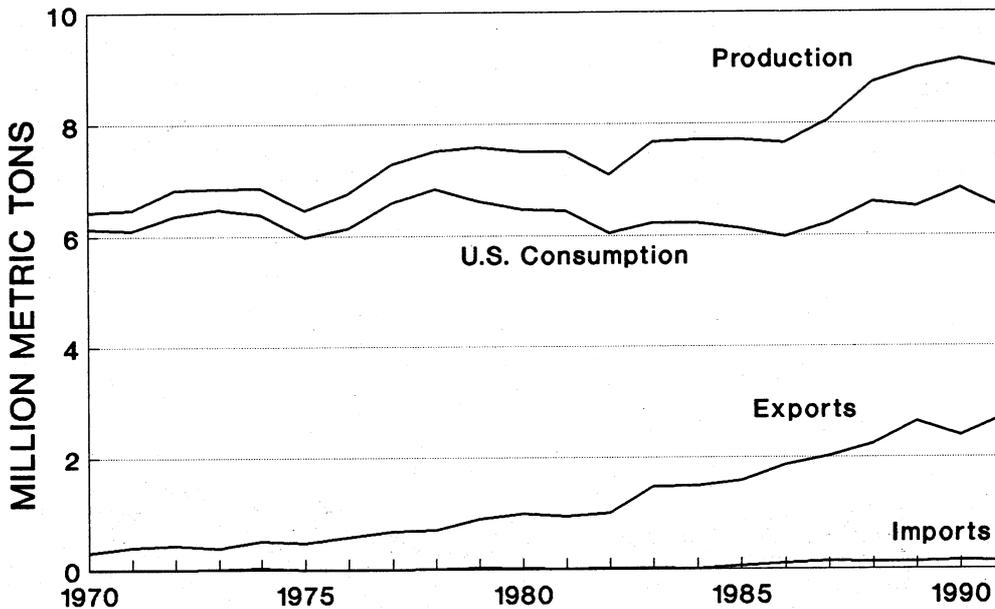


FIGURE 2
SODA ASH SUPPLY-DEMAND RELATIONSHIPS

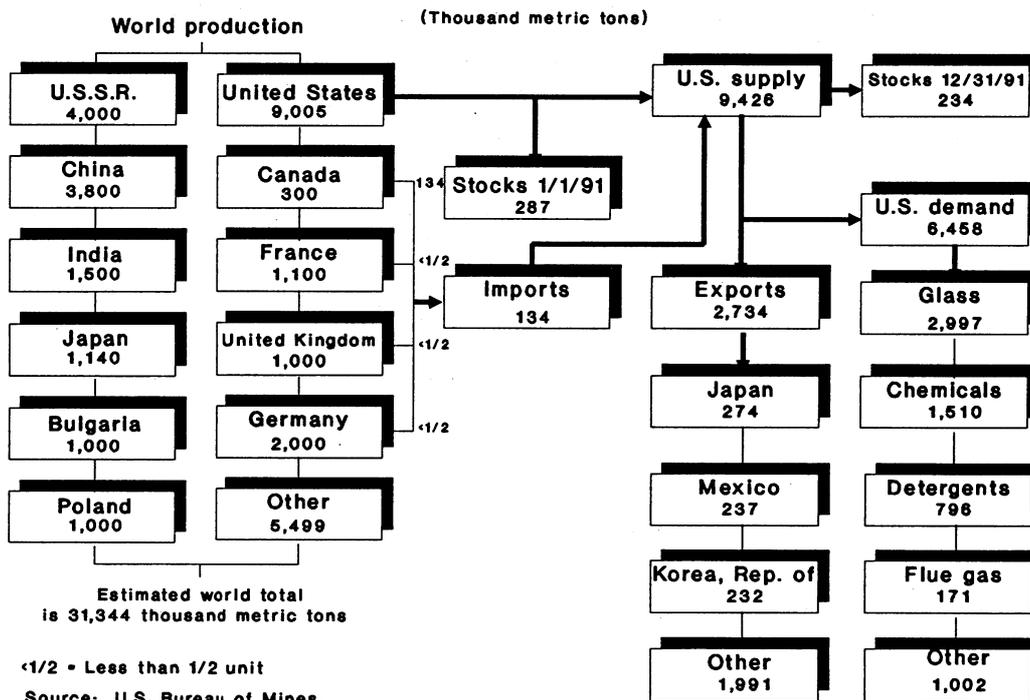
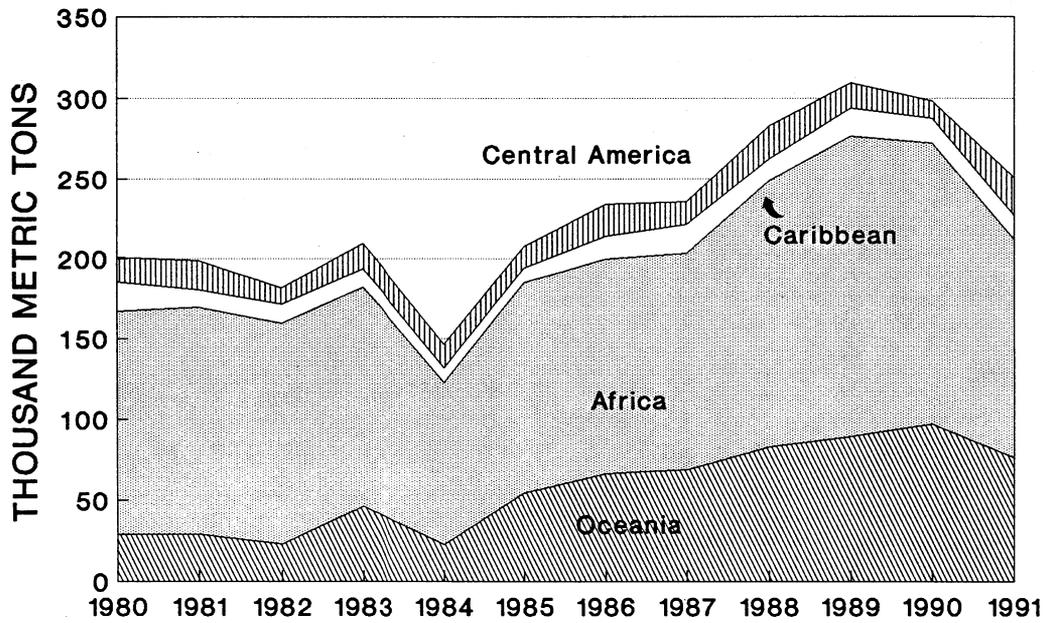
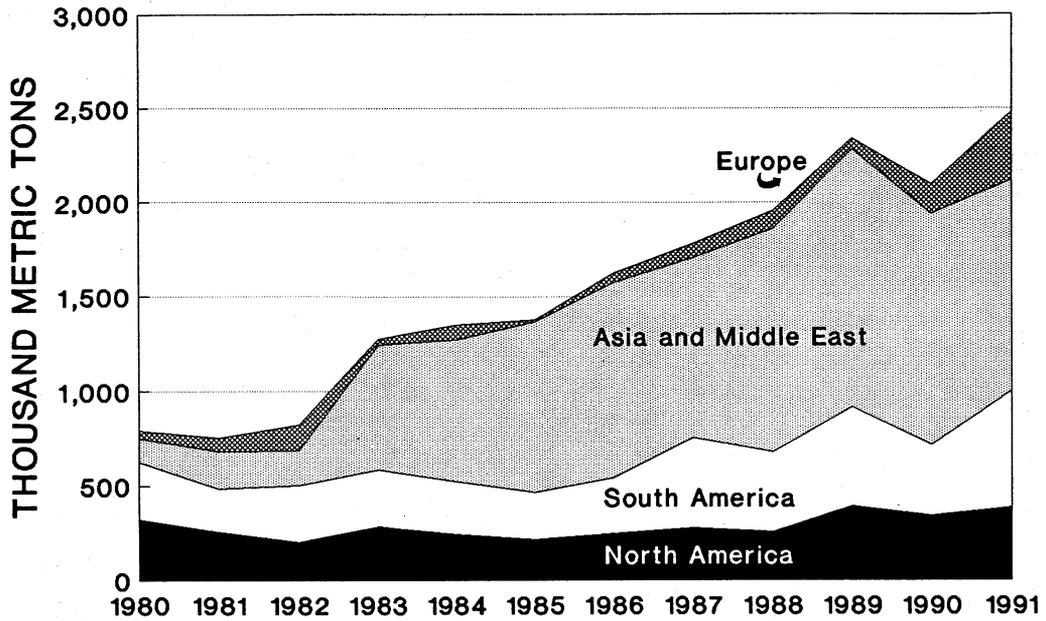


FIGURE 3
U.S. SODA ASH EXPORTS BY, REGION



SODIUM SULFATE

By Dennis S. Kostick

Mr. Kostick, a physical scientist with 13 years of U.S. Bureau of Mines experience, has been the commodity specialist for sodium sulfate since 1979. Domestic survey data were prepared by Carleen Militello, statistical assistant; and international data tables were prepared by William Zajac, Chief, Section of International Minerals.

There are two types of sodium sulfate—natural and byproduct, also known as synthetic. Natural sodium sulfate is produced from naturally occurring brines and crystalline deposits found in California and Texas. It is also found as a constituent of saline lakes, such as the Great Salt Lake in Utah. Synthetic sodium sulfate is recovered as a byproduct from various manufacturing processes. Both types of sodium sulfate have several important and useful applications in various consumer products. In a survey of the top 50 basic organic and inorganic chemicals made in the United States, sodium sulfate ranked 47th in terms of quantity produced.¹

Continuing with this report, all data will be reported in metric units to comply with Public Law 100-418 of August 23, 1988. This Federal law required all Federal agencies to use the metric system of measurement by the end of fiscal year 1992. Although the use of the metric measurement standards was authorized by law since 1866 (Act of July 28, 1866; 14 Statue 339) and the United States was an original signatory party to the 1875 Treaty of the Meter (20 Statue 709), the United States has been the only industrially developed nation that has not universally converted to the metric system from the English system of measurements. As foreign trade of soda ash increases and foreign participation in U.S. joint mining ventures continues, communicating information with an international standard of measurement becomes more important. Two of the three natural sodium sulfate producers have foreign partners and some of the byproduct producers do also.

DOMESTIC DATA COVERAGE

Domestic production and inventory data for natural sodium sulfate are developed by the U.S. Bureau of Mines from monthly and annual surveys of U.S. operations. Of the three natural sodium sulfate operations to which a survey request was sent, all responded, representing 100% of the natural sodium sulfate data used in this report.

Synthetic sodium sulfate data were collected by the U.S. Department of Commerce, Bureau of the Census, from monthly and annual surveys (aggregate data published in Current Industrial Reports, Inorganic Chemicals, M28A and MA28A) of companies engaged in recovering and selling byproduct sodium sulfate. Any revised Census Bureau data have been included using most recent Census Bureau statistics. These data are aggregated with U.S. Bureau of Mines natural sodium sulfate data and included in several tables. (See table 1.)

BACKGROUND

Natural sodium sulfate was known to have been used as a medicine as early as the 16th century. It was first accurately described in 1658 by Johann Rudolph Glauber, a German chemist whose name is still associated with the hydrated crystal, Glauber's salt ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$), and the anhydrous mixed sulfate, Glauberite ($\text{Na}_2\text{SO}_4 \cdot \text{CaSO}_4$).

Glauber and other researchers prepared sodium sulfate by reacting common salt with sulfuric acid. The invention of the Kraft process for making pulp and paper

in 1880 provided the first major industrial market for sodium sulfate.

Definitions, Grades, and Specifications

The following terms are used in the sodium sulfate industry:

Anhydrous Sodium Sulfate.—Refined sodium sulfate or the mineral thenardite (Na_2SO_4). Named for the French chemist, Louis Jacques Thenard, thenardite is a colorless to white mineral with a specific gravity of 2.67 and a hardness of 2.5 to 3. Because of its whiteness and purity, it is used in detergents, pharmaceuticals, dyestuffs, glass, and ceramic glazes. Commercial-grade material has a bulk density of about 1.23 grams per cubic centimeter (77 pounds per cubic foot).

Byproduct Sodium Sulfate.—Synonymous with synthetic sodium sulfate. It is recovered as a byproduct from various chemical and textile manufacturing processes.

Glauber's Salt.—Same as the mineral mirabilite (Latin "sal mirabile" or "wonderful salt"), sodium sulfate decahydrate ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$). The mineral contains 55.9% water of crystallization and forms opaque to colorless needlelike crystals.

High Purity.—Refers to anhydrous sodium sulfate with a purity of 99% or greater. Usually sold to detergent, glass, and textile industries.

Low Purity.—Some processes occasionally produce sodium sulfate that does not meet certain physical or color specifications required by certain consumers despite being a chemically pure product. This grade of sodium sulfate is generally sold to sectors that are not as concerned about whiteness or particle size, such as the pulp and paper industry, at reduced prices.

Natural Sodium Sulfate.—Sodium sulfate obtained from mining crystalline sodium sulfate-bearing minerals or from sodium sulfate-bearing brines.

Salt Cake.—Normally refers to impure sodium sulfate containing 90% to 99% Na_2SO_4 . Because of its impurity or possible discoloration, it usually is sold only to the pulp and paper industry.

Synthetic Sodium Sulfate.—Same as byproduct sodium sulfate.

Sodium sulfate made from natural brine usually contains less than 0.5% total impurities, but that produced as a byproduct of other manufacturing may contain much larger quantities. The material meeting U.S. Pharmacopeia (U.S.P.) specifications and that intended for glassmaking must contain at least 99% sodium sulfate. In addition, glassmakers' grade must be low in iron and heavy metals. Technical grades of sodium sulfate may have from 2% to 6% impurities. Purchases of detergent or rayon-grade sodium sulfate are based primarily on whiteness. Its sodium chloride content may be between 1.5% and 2.0%, and its iron content between 60 and 100 parts per million.

Industry Structure

Three companies produced natural sodium sulfate from a total of three plants in California, Texas, and Utah. The domestic natural sodium sulfate industry supplied about one-half of the total output of U.S. sodium sulfate. Because of the location of these plants, most natural sodium sulfate is marketed in the West and southern gulf areas. Byproduct

material was supplied by 14 companies operating 15 plants primarily in the Midwest and Mid-Atlantic regions. Total rated production capacity in 1991 was 822,000 tons, and the industry operated at 85% of this capacity. (See table 2.)

Geology—Resources

Sodium is the sixth most abundant element in the Earth's crust. Sodium sulfate-bearing mineral deposits are geologically young, mainly of post-glacial age. Sodium sulfate is widespread in occurrence and is a common component of seawater and many saline or alkaline lakes. Economic reserves of natural sodium sulfate are estimated at 3.3 billion tons worldwide. With world production of natural sodium sulfate averaging about 2.6 million tons per year, supplies are sufficient to meet anticipated demand for several centuries. The quantity of synthetic sodium sulfate is dependent on the longevity of the manufacturing firms recovering byproduct sulfate.

Surface depressions or lakes that have no outlets and are fed by spring waters flowing over volcanic rocks containing sulfide minerals often yield soluble sulfide salts that are oxidized by contact with the air to produce sulfates. Some minerals over which the spring water may flow contain the sulfates directly, such as bentonite or gypsum. When an inland lake of this type evaporates and becomes highly concentrated in salts, one of the first salts to precipitate would be mirabilite, also known as Glauber's salt, which has very poor solubility at low temperatures. During seasonal temperature variations, the sulfate will precipitate preferentially to the lake bottom.

Thenardite and mirabilite are the only sodium sulfate minerals that are commercially important. Many economic deposits of sodium sulfate are in the form of crystalline beds of mirabilite such as those found in Canada and the U.S.S.R., which has the world's largest sodium sulfate resource in the Kara-Bogaz-Gol Gulf. Because mirabilite converts to thenardite when exposed to air, its outer surface may develop a thenardite crust.

Some buried sedimentary formations contain very large deposits of thenardite and glauberite, such as the deposit in Villarrubia de Santiago in Spain.

Sodium sulfate is also found dissolved in underground brines in California, Texas, and other parts of the world. The sulfate is usually converted to mirabilite when extracted from the brine by mechanical refrigeration techniques. (See table 3.)

Technology

The technology to mine and process natural sodium sulfate involves mechanical refrigeration or natural chilling to induce crystallization followed by dissolution, filtration, evaporation, and drying. Recovery of byproduct sodium sulfate from chemical processes involves various techniques.

Mining.—Sodium sulfate is extracted from the upper level of the Searles Lake brine in California and is treated separately from the carbonate-rich lower level and mixed layer brines. The subterranean sodium sulfate-bearing brines in western Texas are the simplest of the domestic brine deposits. Mechanical refrigeration is used to extract Glauber's salt crystals from the brine. The Great Salt Lake in Utah also contains valuable quantities of sodium sulfate. Brine from the most concentrated northwest segment of the lake is pumped into solar evaporation ponds on the eastern shore of the lake where sodium chloride first precipitates as the water evaporates. Sodium sulfate crystals precipitate in a fairly pure state when winter weather cools the brine to -1° to 4° C (30° to 40° F). The crystals are picked up by large earth-moving machinery and stored outdoors until further processing to anhydrous sodium sulfate can take place.

Processing.—At Searles Lake, the brine is first cooled at about 16° C (60° F) to precipitate borax crystals, which are removed from the system for subsequent further processing and sale. A second cooling to about 4° C (40° F) precipitates

the sodium sulfate in the form of Glauber's salt. These crystals are separated from the brine on a rotating drum filter. They are then redissolved in fresh water in a vacuum crystallizer. After the second separation and drying, the crystals are about 98.2% sodium sulfate. Additional treatment can obtain a 99.3% purity. Major impurities remaining are sodium chloride, sodium carbonate, and boron.

In Texas, after the crystals are processed in rotary drum vacuum filters and washed, they are melted and dehydrated using mechanical vapor recompression evaporators, which are more energy efficient than triple effect evaporators or submerged gas burners. Final classifying, centrifuging, drying in rotary kilns, and screening converts the Glauber's salt to marketable anhydrous sodium sulfate of 99.7% purity.

Purification and dehydration procedures at the facility on the Great Salt Lake are similar to those of other sodium sulfate plants. The final product results in a purity between 99.5% to 99.7%.

Sodium sulfate is also produced as a byproduct of the production of ascorbic acid, boric acid, cellulose, chromium chemicals, lithium carbonate, rayon, resorcinol, and silica pigments. It is also recovered from certain flue gas desulfurization operations. The Mannheim and Hargreaves furnace processes also produce byproduct sodium sulfate. In the Mannheim furnace, salt and sulfuric acid are reacted to form hydrogen chloride (HCl) and sodium sulfate. The Hargreaves furnace produces HCl and sodium sulfate by the reaction of sulfur dioxide, sodium chloride, air, and water. The Mannheim process is the major method used in Europe, but its use in the United States has decreased considerably since less expensive methods to produce HCl became available.

Recycling.—Because of environmental concerns regarding sulfur emissions from pulp and paper mills, many Kraft pulpers were installing pollution abatement equipment to reduce sulfur losses in the pulping process. This will result in more

sodium sulfate being recycled and less used in batch makeup solutions.

Byproducts and Coproducts

The brines of Searles Lake in California contain sodium sulfate as well as coproduct borax, potassium chloride, sodium chloride, and soda ash. The Great Salt Lake in Utah is a source of magnesium compounds, potassium sulfate, sodium chloride, as well as sodium sulfate.

Some manufacturers of ascorbic acid, boric acid, cellulose, chromium chemicals, lithium carbonate, rayon, resorcinol, and silica pigments produce sodium sulfate as a byproduct of the process. The sodium sulfate is considered a waste product but has marketability.

Economic Factors

Prices.—Producers of natural sodium sulfate tend to market and sell most of their own product, but most synthetic producers use major chemical distributors or chemical supply companies as sales agents. The principal product made and sold by the synthetic sodium sulfate producer is the primary economic factor. Because sodium sulfate is considered a waste product, it will be sold at a price that ensures prompt sales. This practice tends to set the rates at which the natural product can be sold.

The list prices quoted in trade journals or by producers of all grades of sodium sulfate differ from the annual average values reported by the U.S. Bureau of Mines. The value represents the combined amount of total revenue of domestic natural sodium sulfate sold at list prices, spot prices, long-term contracts, discounts, and export divided by the aggregated quantity of sodium sulfate sold. The published value does not necessarily correspond to the posted list price. (See table 4.)

Tariffs.—Import tariffs serve to protect the interests of domestic producers for particular products. For sodium sulfate, a 32.5-cents-per-ton tariff is imposed on

imported anhydrous sodium sulfate from countries having most favored nation (MFN) status and \$2.95 per ton from those with non-MFN status. There are no import tariffs on imported salt cake, regardless of the country of origin.

Royalties.—Sodium sulfate mined on Federal lands is subject to the Mineral Leasing Act of 1920, which provides for royalty payments to the U.S. Government. The royalty is 5% of the quantity or gross value of the output of the product at the point of shipment to market. Each Federal lease also has other costs, such as bonds, acreage rental fees, sodium prospecting permit application fees, and permit bonds. The Searles Lake sodium sulfate deposit is the only resource with active operations that has any Federal leases. Because of the variety of the brine constituents, the operator has a commingling agreement with the U.S. Government to compute royalties.

Depletion Provisions.—Legislation passed by the U.S. Government provides an allowance for the depletion of natural resources, notably timber and minerals. The depletion allowance is an important inducement for companies willing to accept the risk and high cost of mining development. The concept of depletion allowances for minerals is similar to the depreciation of other assets. Although cost depletion and percentage depletion are two methods used to compute depletion deductions, most companies prefer to use the latter. About 100 mineral categories are entitled to percentage depletion. The rates range between 5% and 22% of the gross income from the mineral property, depending on the mineral and location (foreign or domestic), and are subject to a limitation of 50% of the net income of the property. The mineral depletion allowance for natural sodium sulfate is 14% for U.S. companies mining from domestic or foreign sources.

Operating Factors

Operating factors are different for mining companies producing natural

sodium sulfate compared with manufacturing facilities recovering byproduct sodium sulfate. The quantity of synthetic sodium sulfate recovered is directly associated with the production capabilities of the primary industry (e.g., rayon, lithium carbonate, etc.) and the sulfate recovery rates.

Environmental Requirements.—Land usage may become a problem when sodium sulfate is obtained by solar evaporation, as in the case of the Great Salt Lake brines. Large areas of relatively flat land are required to allow for adequate concentration and evaporation. When land values are high, the capital required for land acquisition may increase operating costs. Disposal of the waste liquors from which sodium sulfate was extracted may develop into a major ground water discharge problem in some areas. ReInjection of spent solutions into underground source strata is expensive but often is the only acceptable method of disposal.

Because sodium sulfate is water-soluble, most releases of sodium sulfate to the environment affect water quality rather than air or land quality. These releases are mainly from Kraft pulp mills, which typically discharge between 5 to 15 million kilograms (11 to 33 million pounds) of sodium sulfate per year per site. The resulting drinking water concentrations have been estimated as high as 38.8 milligrams per liter, which is significantly below the maximum concentration level of 250 milligrams per liter set by the National Secondary Drinking Water Standard.

Problems associated with chemical effluents discharged from manufacturing plants that recover sodium sulfate have also caused environmental concerns not attributed to sodium sulfate. The second largest byproduct sodium sulfate facility in the United States at Front Royal, VA, owned by Avtex Fibers Inc., was closed in late 1989 by Federal and State regulatory agencies because of contaminated water discharges containing carbon disulfide and polychlorinated biphenyls (PCB's). These toxic chemicals

were produced from rayon manufacture, not sodium sulfate recovery.

Toxicity.—Sodium sulfate was deleted in early 1989 from the list of toxic chemicals under section 313 of title III of the Superfund Amendments and Reauthorization Act of 1986. The U.S. Environmental Protection Agency determined that there was no evidence that sodium sulfate caused, or could reasonably be anticipated to cause, adverse human health or environmental effects as specified in the act.

Employment.—According to the Bureau of Labor Statistics and industry sources, approximately 300 persons are employed in mining and processing natural sodium sulfate in the United States. Data are not available on the number of personnel employed in recovering byproduct sodium sulfate.

Energy Requirements.—The energy requirements to mine natural sodium sulfate are minimal compared to the amount of energy required to process it. An early U.S. Bureau of Mines energy survey reported that 4.5 million British thermal units (Btu's) was required to produce 1 ton of natural sodium sulfate. With the interest in conserving energy, some technical improvements, such as the installation of mechanical vapor recompression crystallizers, have reduced the overall energy requirement to slightly less than 2 million Btu's per ton of sulfate produced.

Transportation.—All natural sodium sulfate is shipped in bulk or in bags by either rail or truck. The mode of transportation depends on the location of the customer, quantity purchased, and difference in freight rates. Because of the location of the natural producers in the West and Southwest, very little natural sodium sulfate is shipped to the East because transportation rates reduce its competitiveness with synthetic sodium sulfate. Consumers in the Midwest and East tend to rely on synthetic sodium

sulfate produced in various Midwest and Southern locations.

ANNUAL REVIEW

Domestic sodium sulfate production decreased about 2% in 1991 while overall U.S. apparent consumption declined 6%. The slight downturn in production was attributed to the national economic recession that affected some of the industries that recover byproduct sodium sulfate. Although the United States is one of the largest producers in the world of natural and synthetic sodium sulfate, its share has decreased from 23% of world production total in 1980 to 14% in 1991. Figure 1 graphically shows the trend of U.S. production since 1970. Total production has declined 44% since 1970. (See figure 1.)

Issues

The environmental movement in North America continued to adversely affect the North American sodium sulfate industry. Changes toward oxygen-base bleaching chemicals by the pulp and paper industry have reduced the sales by several sodium sulfate suppliers. Some of the chemicals can be produced on-site at various pulp mills. One of the chosen bleaching chemicals, chlorine dioxide, produces sodium sulfate as a byproduct that can be used and partially recycled by the pulp mills. By producing their own sodium sulfate, certain pulp mills would not have to purchase any sodium sulfate.²

Sodium sulfate consumption by the soap and detergent industry, which has been the largest consumer of sodium sulfate, remained stagnant because of product reformulations. In addition, the growing national environmental awareness regarding the volume of packaging material discarded to landfills prompted certain detergent manufacturers to begin making superconcentrated or compact products that are packaged in smaller containers. This reduction in package size minimizes the amount of landfill waste but also reduces the quantity of sodium sulfate used in powdered detergents. Sodium sulfate is

used as a filler in powdered home laundry detergents. (See figure 2.)

Production

U.S. production of sodium sulfate decreased about 2% in 1991 primarily because of stagnant market conditions. Problems in byproduct production in the Southeast cause some tightness in the market. Production was temporarily down at the Bessemer City, NC, plant of Lithium Corp. of America, and a late startup at Cortauld's Le Moyne, AL, plant also caused supply disruptions.³ Reportedly, the Hoffman-LaRoche pharmaceutical plant at Belvidere, NJ, ceased recovering sodium sulfate. Green Bay Packaging Inc., of Green Bay, WI, converted to using recycled paper that eliminated the sodium sulfate recovery operation. W. R. Grace and Co. changed its chelate agent process technology that reduced the quantity of sodium sulfate recovered. The plant is at Nashua, NH.

The United States and Mexico were the largest producers of total sodium sulfate, each representing about 13% of the world total. Spain produced 12%, followed by the U.S.S.R., 11%, and Canada and Germany, 7% each. These six countries accounted for approximately 65% of the world's output of total sodium sulfate, based on obtainable production data. (See tables 5 and 6.)

Consumption and Uses

U.S. sodium sulfate apparent consumption decreased 6% from that of the previous year. Most of the same conditions that affected demand in 1990 remained in 1991. Concern for the environment was the paramount reason behind the stagnant supply and demand situation. Imports for consumption of sodium sulfate, primarily from Canada and Mexico, also declined because of the depressed U.S. markets in which sodium sulfate is consumed.

An estimated 53% of the total sodium sulfate consumed in the United States is for use as a filler in powdered laundry detergents. Many areas in the country have adopted phosphate bans or

limitations because phosphatic detergents contribute to the environmental problems of eutrophication. The affected areas represent about 33% of the U.S. population. In response to this environmental issue, detergent manufacturers have reformulated many of their detergents by switching from sodium tripolyphosphate (STPP) to tetrasodium pyrophosphate, which has the same building power as STPP but requires less to be used, thereby reducing the amount of phosphate released into the environment. These reformulations used more sodium sulfate as filler, which was beneficial to the sodium sulfate industry.

Sodium sulfate consumption decreased in the Kraft pulping industry because of the economic recession affecting the paper industry and recycling of paper products. Kraft pulping represented about 83% of the domestic pulp market in 1991. Public awareness about the environmental issue of nondegradable plastic packaging made many people prefer brown paper grocery bags (produced by the Kraft process), which degrade in landfills much more readily than plastic bags. Kraft pulping represents about 27% of the total demand for sodium sulfate. (See figure 3.)

Stocks

Yearend inventories of natural sodium sulfate stored by the three producers were 35,436 tons, which was a 9% decrease over that of the previous year. The material stockpiled was anhydrous sodium sulfate. Synthetic sodium sulfate was marketed mainly through major chemical distributors, which have separate storage facilities from the producers.

Atochem North America Inc. installed a new bagging system to handle its natural sodium sulfate supplies. The operation is at Charlotte, NC, and has a capacity to package more than 40,000 tons of product annually. Sodium sulfate can be packaged and stockpiled at the facility, which is closer to several of Atochem's customers.

Markets and Prices

The average value declined from \$96.63 per metric ton (\$87.66 per short ton) to \$87.34 per metric ton (\$79.23 per short ton) for bulk sodium sulfate, f.o.b. mine or plant.

As of December 1, Atochem North America increased its prices for natural sodium sulfate by \$5 per ton. The new prices, per short ton, are: bulk detergent grade, \$110; bulk glass grade, \$110; bulk paper grade, \$105; 100-pound bags detergent grade, \$137; 50-pound bags detergent grade, \$144; SS 2,000 pounds, \$137.50; and SS 1,350 pounds, \$144.45.⁴ (See table 7.)

Foreign Trade

U.S. exports of 103,000 tons were 66% higher in 1991 when compared with those of the previous year. The Republic of South Korea received almost 3 times the quantity of sodium sulfate in 1991 than it imported in 1990. This increase was because of Oriental Chemical Industries (OCI), which became a joint-venture partner with North American Chemical Co. at Searles Lake, CA. OCI was taking its share of product back to Korea for consumption.

Canada and Mexico supplied about 98% and about 2%, respectively, of total U.S. sodium sulfate imports. Small shipments were sent to the United States from Brazil, Finland, Germany, and Japan. Although the United States had a net import reliance of about 8%, most imports were less expensive to consumers than products from domestic sources, especially when overland shipping costs are considered.

Approximately 33% of the total quantity was shipped to Australia; Chile, 15%; Colombia, 14%; and New Zealand, 8%. Most was in the form of low-purity salt cake. (See tables 8, 9, 10, 11, and figure 4.)

World Review

Industry Structure.—About 52% of the world sodium sulfate production in 1991 was from natural sources; the balance

was represented by synthetic sodium sulfate recovered from various chemical and manufacturing processes. Although the U.S. Bureau of Mines collects or estimates data from 28 sodium sulfate-producing countries, other countries are known or assumed to have produced synthetic sodium sulfate, but production statistics are not reported, and available information is inadequate to make reliable estimates of output. (See table 12.)

Capacity.—The data in table 2 are rated capacities for domestic natural operations and byproduct recovering facilities in 1991. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

Mine capacity for natural sodium sulfate is derived from available company data on ore throughput to the refinery. The ore refers to mined crystalline sodium sulfate, harvested precipitate, or sodium sulfate-bearing brines. Refinery capacity for natural sodium sulfate pertains to the total amount of anhydrous sodium sulfate that the plant is capable of processing from the ore. Synthetic sodium sulfate refining capacity is dependent on the production capabilities of the primary industry and the sodium sulfate recovery rates.

Canada.—Agassiz Resources Ltd., which is the second largest natural sodium sulfate producer in Canada, closed its Hardene, Saskatchewan, facility in April. By July, Agassiz's plants at Cabri, Saskatchewan, and Metiskow, Alberta, had suspended operations because of economic conditions.⁵

Iran.—A 20,000-ton-per-year synthetic sodium sulfate plant is under construction

near Ghazvin, 250 kilometers west of Teheran. Alborz Chemical Complex Co., a subsidiary of Alborz Investment Corp., the owner, planned to sell the sodium sulfate primarily to the local detergent industry. Startup of the facility was planned for 1992 or 1993.⁶

United Kingdom.—Imperial Chemical Industries licensed a new electrolytic process that recycles sulfuric acid and caustic soda from liquid wastes containing sodium sulfate. The sodium sulfate had been discharged as effluent to streams and rivers, which were becoming environmentally contaminated. Instead of purifying and selling the sodium sulfate byproduct, which had declining markets, the material could now be converted to salable acids.⁷

OUTLOOK

U.S. natural and synthetic sodium sulfate production and consumption decreased 44% and 48%, respectively, from those of 1980 to 1991. The decreases were because of changes in the recovery operations of consuming industries mandated by environmental legislation requiring reductions in sulfate emissions and declining use of sodium sulfate in powdered laundry detergents. Although production has been relatively flat since about 1982, domestic consumption of sodium sulfate has fluctuated primarily due to detergent reformulations that contain reduced quantities of sodium sulfate. U.S. consumption is expected to decline further, or less pessimistically remain flat, in the next few years.

The United States is a very important market for Canadian sodium sulfate. In 1991, 45% of Canadian output was exported to the United States. If domestic markets continue to decline, Canadian producers would encounter financial hardships and would be forced to look for more distant export opportunities. Sodium sulfate imports from Mexico are relatively minor compared to its total production capability; therefore, any erosion of U.S. domestic consumption

would not affect Mexican producers significantly.

Production

The changes in the domestic demand situation has prompted several byproduct sodium sulfate producers to consider changing their process technology that would alter the composition of byproduct wastes. For example, hydrochloric acid plants could use potash, rather than salt, to recover potassium sulfate instead of sodium sulfate. Potassium sulfate is a fertilizer used for tobacco, fruits, nuts, and other crops.

A new method to produce byproduct sodium sulfate began in mid-1991. Tonolli Canada Ltd. started to produce about 7,000 tons per year of sodium sulfate from its battery recycling operation in Mississauga, Ontario, Canada. Its technology will be used by Doe Run Co., at Boss, MO. This facility will recover about 12,000 tons of sodium sulfate annually.⁸ Reportedly, other battery recycling plants are planned that will also recover sodium sulfate. They include GNB Batteries Inc. of Fort Valley, GA, and Asarco. BASF Corp. is reportedly evaluating recovering sodium sulfate from one of its chemical operations. Formosa Plastics Corp. planned to construct a rayon plant near Wallace, LA, that would produce about 75,000 tons of synthetic sodium sulfate annually. These new byproduct operations will have an effect on the other byproduct plants and natural sodium sulfate producers that market sodium sulfate into those regions.

Detergents

The use of sodium sulfate as a filler appears to have peaked in 1989. In 1991, major detergent manufacturers continued making more superconcentrated detergent products rather than the traditional large boxes filled with bulk detergents containing up to 20% sodium sulfate as filler. This change, initiated by environmental considerations, will further reduce sales of sodium sulfate in the near future unless consumers do not purchase

the more expensive superconcentrate detergents because of the higher cost. If the economic recession continues, which affects consumer spending, less expensive powdered detergents containing sodium sulfate may be reintroduced at the expense of the more expensive concentrated and liquid products. In addition, liquid laundry detergents that do not contain any sodium sulfate continued to make up about 40% of the home laundry market.

Pulp and Paper

The economic recession that began in late 1990 and lasted throughout 1991 affected sodium sulfate sales to the pulp and paper sector, resulting in reduced sodium sulfate consumption. Environmental concerns regarding sulfur emissions prompted many Kraft pulpers to install pollution control equipment to reduce sulfur losses in the pulping process. Furthermore, many Kraft pulpers are changing their bleaching chemicals to abide by the new environmental regulations. Production of sodium chlorate, which is used to make chloride dioxide, will increase as the demand for oxygen-base bleaching chemicals rises. The process will produce sodium sulfate as a byproduct, thereby reducing the demand for saltcake. Recycling of brown paper bags made by the Kraft process will also reduce sodium sulfate consumption in the future.

¹Chemical and Engineering News. Facts and Figures for the Chemical Industry. V. 69, No. 25, p. 31.

²_____. Paper Industry Changes Shake Supplier Lineup. V. 69, No. 45, pp. 15-16.

³Chemical Marketing Reporter. Sodium Sulfate. V. 240, No. 12, p. 30.

⁴_____. Bases and Salts, Sodium Sulfate. V. 240, No. 25, p. 29.

⁵_____. Detergent Compact Shift Makes Sulfate Outlook Grim. V. 239, No. 17, p. 5.

⁶Industrial Minerals. New Synthetic Sodium Sulfate Plant. No. 286, p. 29.

⁷_____. Company News. ICI Cleans Up Na₂SO₄ Waste. No. 286, p. 28.

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TABLE 1
SALIENT SODIUM SULFATE STATISTICS

(Thousand metric tons and thousand dollars)

	1987	1988	1989	1990	1991
United States:					
Production ¹	725	743	685	713	696
Value ²	\$69,289	\$64,545	\$62,703	\$64,244	\$60,825
Exports	111	77	62	62	103
Value	\$10,554	\$8,737	\$6,241	\$6,704	\$11,495
Imports for consumption	125	136	173	162	157
Value	\$10,363	\$11,962	\$13,990	\$13,155	\$13,807
Stocks, Dec. 31: Producers	50	54	24	39	35
Apparent consumption	755	798	825	798	754
World: Production	³ 4,895	⁴ 4,943	⁴ 4,931	⁴ 4,870	⁴ 4,837

³Estimated. ⁴Revised.

¹Includes natural and synthetic. Total production data for synthetic sodium sulfate, obtained from the Bureau of the Census, was revised in Dec. 1990 M28A Inorganic Chemicals, Current Industrial Report.

²The value for synthetic sodium sulfate is based upon the average value for natural sodium sulfate.

TABLE 2
PRODUCERS OF NATURAL AND SYNTHETIC SULFATE, IN 1991

Product and company	Plant nameplate capacity (thousand metric tons)	Plant location	Source
Sodium sulfate, natural:			
Great Salt Lake Minerals & Chemicals Corp.	45	Ogden, UT	Salt lake brine.
North American Chemical Co., ¹ Westend plant	218	Trona, CA	Dry lake brine.
Ozark-Mahoning Co. ²	141	Seagraves, TX	Do.
Total	404		
Sodium sulfate, synthetic:			
BASF	34	Lowland, TN	Rayon manufacture.
Climax Chemical Co.	45	Hobbs, NM	Hydrochloric acid manufacture.
Courtaulds North America Inc.	45	La Moyné, AL	Rayon manufacture.
Cyprus Specialty Metals	16	Kings Mountain, NC	Lithium carbonate.
W. R. Grace & Co. Organic Chemicals Div.	8	Nashua, NH	Chelating agents.
J. M. Huber	32	Etowah, TN	Silica pigment.
Do.	14	Havre de Grace, MD	Do.
Indspec Chemical Corp.	35	Petrolia, PA	Resorcinol manufacture.
Lithium Corp. of America	41	Bessemer City, NC	Lithium carbonate.
North American Rayon Corp.	14	Elizabethton, TN	Rayon manufacture.
Occidental Chemical Corp.	109	Castle Hayne, NC	Sodium dichromate manufacture.
Public Service of New Mexico	6	Waterflow, NM	Flue gas desulfurization.
Teepak, Inc.	6	Danville, IL	Cellulose manufacture.
Texaco Chemical Co.	3	Delaware City, DE	Flue gas desulfurization.
Total	408		
Grand total	812		

¹Purchased Nov. 30, 1990, from Kerr-McGee Chemical Corp.

²Ozark's Brownfield plant, owned by Atochem North America (formerly Penwalt), was placed on standby in Sept. 1987; 64,000 tons of capacity is not included in total industry capacity.

TABLE 3
WORLD NATURAL SODIUM
SULFATE RESERVES AND
RESERVE BASE

(Million metric tons)

	Reserves	Reserve base ¹
North America:		
Canada	84	272
Mexico	165	227
United States	857	1,361
Total	1,106	1,860
Europe:		
Spain	180	272
U.S.S.R.	1,814	2,268
Total	1,994	2,540
Africa:		
Botswana	188	227
World total²	3,300	4,600

¹The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources). These definitions of reserves and reserve base are published in U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals."

²Data do not add to total shown because of independent rounding.

NOTE.—Resources of sodium sulfate are known to also exist in Antarctica, Argentina, Chile, India, Iran, Italy, Mongolia, Romania, the Republic of South Africa, and Turkey. Production of synthetic sodium sulfate is dependent on the supply and demand of the primary product.

TABLE 4
TIME-VALUE RELATIONSHIPS FOR SODIUM SULFATE

Year	Average annual value, ¹ dollars per ton			
	Natural sodium sulfate			
	Actual value		Based on constant 1991 dollars ²	
	Short ton	Metric ton	Short ton	Metric ton
1970	18.28	20.15	60.93	67.16
1971	16.00	17.64	50.59	55.77
1972	16.26	17.92	49.03	54.05
1973	17.26	19.03	48.90	53.90
1974	23.99	26.44	62.51	68.91
1975	41.48	45.72	98.64	108.73
1976	49.25	54.29	110.18	121.45
1977	46.09	50.81	96.47	106.34
1978	46.06	50.77	89.37	98.51
1979	55.69	61.39	99.48	109.66
1980	62.42	68.81	101.86	112.28
1981	71.03	78.30	105.33	116.11
1982	83.00	91.49	115.88	127.74
1983	93.30	102.85	125.18	137.99
1984	92.16	101.59	118.49	130.61
1985	92.19	101.62	114.26	125.95
1986	86.11	94.92	103.97	114.61
1987	86.72	95.59	101.46	111.84
1988	78.81	86.87	88.75	97.83
1989	83.05	91.55	89.64	98.81
1990	87.66	96.63	90.84	100.13
1991	79.23	87.34	79.23	87.34

¹Based on the average valuation by producers of their annual total production and reported sales. The values incorporate the price differences changed by producers for the same finished product sold in bulk at the plant.

²Final 1991 implicit price deflators for 1991 are based on gross domestic product and not gross national product, which was used previously. Based on 1987=100.

TABLE 5
SODIUM SULFATE SUPPLY-DEMAND RELATIONSHIPS¹

(Thousand metric tons)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
World Production											
United States	1,008	784	776	791	736	763	725	743	685	713	696
Rest of world	3,693	3,337	3,306	3,611	3,773	3,846	4,170	4,200	4,246	4,157	4,141
Total	4,701	4,121	4,082	4,402	4,509	4,609	4,895	4,943	4,931	4,870	4,837
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic sources	1,008	784	776	791	736	763	725	743	685	713	696
Imports	249	357	311	240	177	171	125	136	172	162	157
Industry stocks, Jan. 1 ²	30	60	27	44	54	28	65	50	54	24	39
Total U.S. supply	1,287	1,201	1,114	1,075	967	962	915	929	911	899	892
Distribution of U.S. supply:											
Industry stocks, Dec. 31 ²	60	27	44	54	28	65	50	54	24	39	35
Exports	112	101	83	69	108	101	111	77	62	62	103
Industrial demand	1,115	1,073	987	952	831	796	754	798	825	798	754
U.S. DEMAND PATTERN ³											
Glass	62	54	50	49	48	48	45	48	33	32	36
Pulp and paper	508	490	464	454	445	239	226	239	231	223	200
Soaps and detergents	435	426	425	363	318	414	392	415	495	479	400
Other ³	110	103	48	86	20	95	91	96	66	64	118
Total U.S. primary demand	1,115	1,073	987	952	831	796	754	798	825	798	754
VALUES ⁴											
Average annual value per short ton ⁵	\$71.03	\$83.30	\$93.30	\$92.16	\$92.19	\$86.11	\$86.72	\$78.81	\$83.05	\$87.66	\$79.23
Average annual value per metric ton	\$78.30	\$91.49	\$102.85	\$101.59	\$101.62	\$94.92	\$95.59	\$86.87	\$91.55	\$96.63	\$87.34

⁴Estimated using data from "Chemical Profile" issues on sodium sulfate by Chemical Marketing Reporter for 1980, 1983, 1986, and 1989. ⁵Revised.

¹Natural and synthetic except where noted. Synthetic sodium sulfate data obtained from the Bureau of the Census are revised periodically and may differ from previous published reports by the U.S. Bureau of Mines. World production data also are periodically revised on receipt of updated information.

²Natural sodium sulfate only.

³Includes ceramics, chemicals (potassium sulfate, sodium hyposulfite, sodium sulfide, sodium silicate, and sodium aluminum sulfate), feed supplements, printing inks, sulfonated oils, textile dyeing, veterinary medicines, and viscose sponges.

⁴Dollars per ton for natural sodium sulfate, f.o.b. mine or plant.

⁵Although data from 1990 and thereafter will be published in metric units, historical values based on short will continue to be published for reference.

TABLE 6
SYNTHETIC AND NATURAL SODIUM SULFATE¹ PRODUCED IN THE UNITED STATES

(Thousand metric tons and thousand dollars)

Year	Synthetic and natural ² (quantity)			Synthetic	Natural	
	Lower purity ³ (99% or less)	High purity	Total ⁴	Quantity	Quantity	Value
1970	509	737	1,246	703	543	10,932
1971	466	765	1,231	607	624	11,008
1972	477	727	1,204	568	636	11,396
1973	481	824	1,305	695	610	11,597
1974	513	710	1,223	602	621	16,411
1975	391	722	1,113	508	605	27,667
1976	422	695	1,117	516	601	32,655
1977	614	474	1,088	511	577	29,313
1978	599	461	1,060	511	549	27,865
1979	555	462	1,017	533	484	29,689
1980	613	421	1,033	504	529	36,389
1981	604	404	1,008	456	552	43,186
1982	420	364	784	W	W	W
1983	388	388	776	392	384	39,425
1984	388	403	791	396	395	40,125
1985	340	396	736	383	353	35,860
1986	328	435	763	404	359	34,102
1987	312	413	725	379	346	33,086
1988	312	431	743	382	361	31,377
1989	291	394	685	345	340	31,104
1990	345	368	713	364	349	33,748
1991	354	342	696	342	354	30,904

Revised. W Withheld to avoid disclosing company proprietary data.

¹All quantities converted to 100% Na₂SO₄ basis.

²Current Industrial Reports, Inorganic Chemicals, Bureau of the Census. Revisions from 1988 Annual (Preliminary), MA28A, Nov. 1989, p. 11.

³Includes Glauber's salt.

⁴Data may not add to totals shown because of independent rounding.

TABLE 7
SODIUM SULFATE YEAREND PRICES

	1990	1991	
Sodium sulfate (100% Na₂SO₄):			
East, bulk, carlot, works, freight equalized	per ton	\$113.00-\$114.00	\$113.00-\$114.00
Gulf, bulk, carlot, same basis	do.	90.00- 105.00	110.00
West, bulk, carlot, same basis	do.	122.00	127.00
Salt cake (100% Na₂SO₄):			
East, bulk, f.o.b. works	do.	65.00- 62.00	72.00
West, same basis	do.	90.00- —	—

Sources: Chemical Marketing Reporter. Current Prices of Chemicals and Related Materials. V. 238, No. 27, Dec. 31, 1990, p. 31, and V. 240, No. 27, Dec. 30, 1991, p. 31.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF SODIUM SULFATE

(Thousand metric tons and thousand dollars)

Year	Disodium sulfate, salt cake ^{1 2}		Disodium sulfate, other ³		Total ⁴	
	Quantity	Value ⁵	Quantity	Value ⁵	Quantity	Value ⁵
1987	34	2,189	92	8,173	125	10,363
1988	27	1,930	109	10,034	136	11,962
1989	41	3,350	132	10,641	173	13,990
1990	40	3,277	121	9,879	162	13,155
1991	57	5,139	100	8,668	157	13,807

¹Beginning in 1989, import data were reclassified under the Harmonized Tariff System. Salt cake is HTS No. 283311000. In prior years, salt cake was under TSUSA No. 4214200.

²Includes Glauber's salt as follows: 1987-666 tons (\$38,318); and 1988-604 tons (\$16,963). TSUSA No. was 4214600.

³Harmonized Tariff System No. 2833115000 in 1989, changed to No. 2833115010 in 1990; TSUSA No. 4214400 for prior years.

⁴Data may not add to totals shown because of independent rounding.

⁵C.i.f. value at U.S. ports.

Source: Bureau of the Census.

TABLE 9
U.S. IMPORTS OF SODIUM SULFATE, BY COUNTRY

Country	Disodium sulfate, salt cake ¹		Disodium sulfate, other ²		Total	
	Quantity (metric tons)	Value ³ (dollars)	Quantity (metric tons)	Value ³ (dollars)	Quantity (metric tons)	Value ³ (dollars)
1990:						
Brazil	122	21,045	—	—	122	21,045
Canada	40,117	3,220,484	103,164	8,584,982	143,281	11,805,466
Finland	28	9,794	—	—	28	9,794
Germany, Federal Republic of	14	1,426	—	—	14	1,426
Ireland	1	5,447	—	—	1	5,447
Japan	40	18,407	—	—	40	18,407
Mexico	—	—	18,179	1,293,881	18,179	1,293,881
Total	40,322	3,276,603	121,343	9,878,863	161,665	13,155,466
1991:						
Brazil	133	20,839	—	—	133	20,839
Canada	56,956	5,062,033	96,025	8,375,281	152,981	13,437,314
Finland	22	4,553	—	—	22	4,553
Germany, Federal Republic of	179	17,939	—	—	179	17,939
Japan	58	33,592	—	—	58	33,592
Mexico	—	—	3,527	292,506	3,527	292,506
Total	57,348	5,138,956	99,552	8,667,787	156,900	13,806,743

¹Beginning in 1989, import data were reclassified under the Harmonized Tariff System. Salt cake is HTS No. 283311000. In prior years, salt cake was under TSUSA No. 4214200.

²Harmonized Tariff System No. 2833115000 in 1989, changed to No. 2833115010 in 1990. TSUSA No. 4214400 for prior years.

³C.i.f. value at U.S. ports.

Source: Bureau of the Census.

TABLE 10
U.S. EXPORTS OF SODIUM SULFATE

(Thousand metric tons and thousand dollars)

Year	Disodium sulfate, salt cake ¹		Disodium sulfate, other ²		Total ³	
	Quantity	Value ⁴	Quantity	Value ⁴	Quantity	Value ⁴
1987	96	8,882	15	1,672	111	10,554
1988	62	5,128	15	3,609	77	8,737
1989	60	5,409	2	832	62	6,241
1990	61	6,092	1	612	62	6,704
1991	82	8,316	21	3,179	103	11,495

¹Prior to 1989, salt cake was Schedule B No. 4214200. In 1989, it was reclassified under the Harmonized Tariff System as HTS No. 2833111000.

²Prior to 1989, other sodium sulfate was Schedule B No. 4214500. In 1989, it is listed as HTS No. 2833115000.

³Data may not add to totals shown because of independent rounding.

⁴C.i.f. value at U.S. ports.

Source: Bureau of the Census.

TABLE 11
U.S. EXPORTS OF SODIUM SULFATE, BY COUNTRY

Country	Disodium sulfate, salt cake ¹		Disodium sulfate, other ²		Total ³	
	Quantity (metric tons)	Value ⁴ (dollars)	Quantity (metric tons)	Value ⁴ (dollars)	Quantity (metric tons)	Value ⁴ (dollars)
1990:						
Australia	32,628	3,468,288	—	—	32,628	3,468,288
Bahrain	—	—	9	19,358	9	19,358
Brazil	—	—	4	15,707	4	15,707
Canada	375	50,141	—	—	375	50,141
China	—	—	17	24,339	17	24,339
Colombia	4,418	246,519	—	—	4,418	246,519
Costa Rica	—	—	18	12,730	18	12,730
Denmark	—	—	5	11,660	5	11,660
Dominican Republic	—	—	138	40,721	138	40,721
France	—	—	4	17,280	4	17,280
Germany, Federal Republic of	—	—	5	12,325	5	12,325
Hong Kong	—	—	47	61,458	47	61,458
Indonesia	—	—	30	24,000	30	24,000
Italy	—	—	9	63,318	9	63,318
Japan	—	—	15	21,025	15	21,025
Korea, Republic of	5,586	633,418	—	—	5,586	633,418
Mexico	334	35,802	249	84,000	583	119,802
Netherlands	—	—	1	3,759	1	3,759
New Zealand	10,585	946,663	—	—	10,585	946,663
Panama	70	12,125	—	—	70	12,125
Portugal	—	—	103	63,280	103	63,280
Singapore	420	43,560	27	33,016	447	76,576
Spain	—	—	1	3,306	1	3,306
Switzerland	—	—	6	4,222	6	4,222
Taiwan	—	—	181	77,734	181	77,734
Thailand	6,205	639,117	—	—	6,205	639,117
United Kingdom	—	—	16	18,661	16	18,661
Venezuela	160	16,496	—	—	160	16,496
Total³	60,781	6,092,129	885	611,899	61,666	6,704,028
1991:						
Australia	34,172	3,474,861	—	—	34,172	3,474,861
Belize	19	3,239	—	—	19	3,239
Brazil	—	—	4	12,813	4	12,813
Canada	856	97,264	—	—	856	97,264
Chile	15,262	1,369,796	—	—	15,262	1,369,796
China	—	—	38	151,748	38	151,748
Colombia	4,993	353,474	9,130	614,288	14,123	967,762
Dominican Republic	—	—	420	105,512	420	105,512
Ecuador	—	—	14	13,477	14	13,477
Egypt	54	15,000	—	—	54	15,000
Germany, Federal Republic of	—	—	5	22,844	5	22,844
Hong Kong	—	—	29	24,152	29	24,152
Israel	—	—	2	11,060	2	11,060
Italy	—	—	29	10,211	29	10,211

See footnotes at end of table.

TABLE 11—Continued
U.S. EXPORTS OF SODIUM SULFATE, BY COUNTRY

Country	Disodium sulfate, salt cake ¹		Disodium sulfate, other ²		Total ³	
	Quantity (metric tons)	Value ⁴ (dollars)	Quantity (metric tons)	Value ⁴ (dollars)	Quantity (metric tons)	Value ⁴ (dollars)
Jamaica	—	—	13	22,001	13	22,001
Japan	—	—	445	216,868	445	216,868
Korea, Republic of	5,417	650,067	9,374	1,176,924	14,791	1,826,991
Malaysia	—	—	1	3,649	1	3,649
Mexico	223	30,941	726	257,472	949	288,413
Netherlands	—	—	2	8,055	2	8,055
New Zealand	8,160	765,694	460	400,448	8,620	1,166,142
Nigeria	5,071	701,810	—	—	5,071	701,810
Philippines	35	6,781	14	7,897	49	14,678
South Africa, Republic of	—	—	20	29,049	20	29,049
Switzerland	—	—	18	7,924	18	7,924
Taiwan	25	5,000	18	31,115	43	36,115
United Kingdom	—	—	18	8,735	18	8,735
Venezuela	7,862	842,248	83	42,686	7,945	884,934
Total³	82,149	8,316,175	20,863	3,178,928	103,012	11,495,103

¹Prior to 1989, salt cake was Schedule B No. 42114200. In 1989, it was reclassified under the Harmonized Tariff System as HTS No. 2833111000.

²Prior to 1989, other sodium sulfate was Schedule B No. 4214500. In 1989, it is listed as HTS No. 2833115000.

³Data may not add to totals shown because of independent rounding.

⁴F.a.s. value at U.S. ports.

Source: Bureau of the Census.

TABLE 12
SODIUM SULFATE: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991 ³
Natural:					
Argentina	27,483	15,341	10,281	⁴ 11,000	10,500
Canada	342,076	330,971	³ 327,000	³ 347,000	340,000
Chile ³	12,406	15,879	¹ 10,245	¹ 13,497	13,000
China ⁴	18,000	27,000	27,000	27,000	28,000
Egypt	42,484	⁴ 42,500	45,677	⁴ 41,418	41,000
Iran	² 264,442	² 213,521	¹ 184,848	¹ 176,951	180,000
Mexico ⁵	486,245	502,448	603,551	⁶ 650,000	650,000
Netherlands ⁶	22,000	22,000	22,000	22,000	22,000
South Africa, Republic of	241	255	15	² 20	20
Spain	475,255	⁴ 450,000	⁴ 450,000	¹ ⁴ 430,000	450,000
Turkey	82,628	79,427	¹ ⁸ 85,000	¹ ⁸ 85,000	85,000
U.S.S.R. ⁶	365,000	375,000	365,000	³ 340,000	320,000
United States (sold by producers)	346,140	361,345	339,761	349,256	⁷ 353,836
Total	²2,484,400	²2,435,687	²2,470,378	²2,493,142	2,493,356
Synthetic:					
Austria ⁶	109,000	118,000	120,000	120,000	120,000
Belgium ⁶	260,000	255,000	255,000	250,000	250,000
Brazil ⁶	7,000	9,000	9,000	9,000	9,000
Chile ⁸	48,000	47,000	⁵ 56,245	⁵ 59,509	60,000
Finland ⁶	35,000	35,000	³ 33,000	³ 33,000	33,000
France ⁶	115,000	154,000	¹ 120,000	120,000	120,000
Germany, Federal Republic of:					
Eastern states	179,000	180,000	175,000	¹ 170,000	160,000
Western states	164,000	¹ 175,000	¹ 172,000	¹ 167,000	165,000
Total	343,000	355,000	347,000	337,000	325,000
Greece ⁶	7,000	7,000	⁶ 6,000	⁶ 6,000	6,000
Hungary ⁶	9,000	9,000	9,000	⁸ 8,000	8,000
Italy ⁶	80,000	127,000	130,000	130,000	125,000
Japan	255,313	246,541	256,393	² 253,131	254,000
Netherlands ⁶	15,000	15,000	15,000	15,000	15,000
Pakistan ⁶	1,000	1,000	1,000	1,000	1,000
Portugal ⁶	55,000	54,000	55,000	55,000	50,000
Spain ⁶	165,000	165,000	165,000	160,000	150,000
Sweden ⁶	100,000	100,000	100,000	100,000	100,000
Turkey ⁶	27,000	27,000	27,000	27,000	30,000
U.S.S.R. ⁶	260,000	270,000	270,000	² 250,000	220,000
United Kingdom ⁶	90,000	90,000	90,000	90,000	90,000
United States ⁹	391,541	381,517	345,555	315,604	⁷ 342,576
Yugoslavia	37,556	41,479	⁵ 50,333	³ 37,953	35,000
Total	2,410,410	²2,507,537	²2,460,526	²2,377,197	2,343,576
Grand total	⁴4,894,810	⁴4,943,224	⁴4,930,904	⁴4,870,339	4,836,932

⁵Estimated. ⁷Revised.

¹Table includes data available through May 6, 1992.

²In addition to the countries listed, China, Norway, Poland, Romania, and Switzerland are known or are assumed to have produced synthetic sodium sulfate, and other unlisted countries may have produced this commodity, but production figures are not reported, and general information is not adequate for the formulation of reliable estimates of output levels.

³Natural mine output, excluding byproduct output from the nitrate industry, which is reported separately under "Synthetic" in this table.

⁴Byproduct sodium sulfate is known to be recovered but reliable data are not available; not included under "Synthetic."

⁵Total output as reported in the Anuario Estadístico de la Industria Química Mexicana.

⁶Conjectural estimates based on 1968 information on natural sodium sulfate and general economic conditions.

⁷Reported figure.

⁸Byproduct of nitrate industry.

⁹Derived approximate figures; data presented are the difference between reported total sodium sulfate production (natural and synthetic not differentiated) and reported natural sodium sulfate sold by producers (reported under "Natural" in this table).

FIGURE 1
PRODUCTION OF SODIUM SULFATE NATURAL VERSUS SYNTHETIC

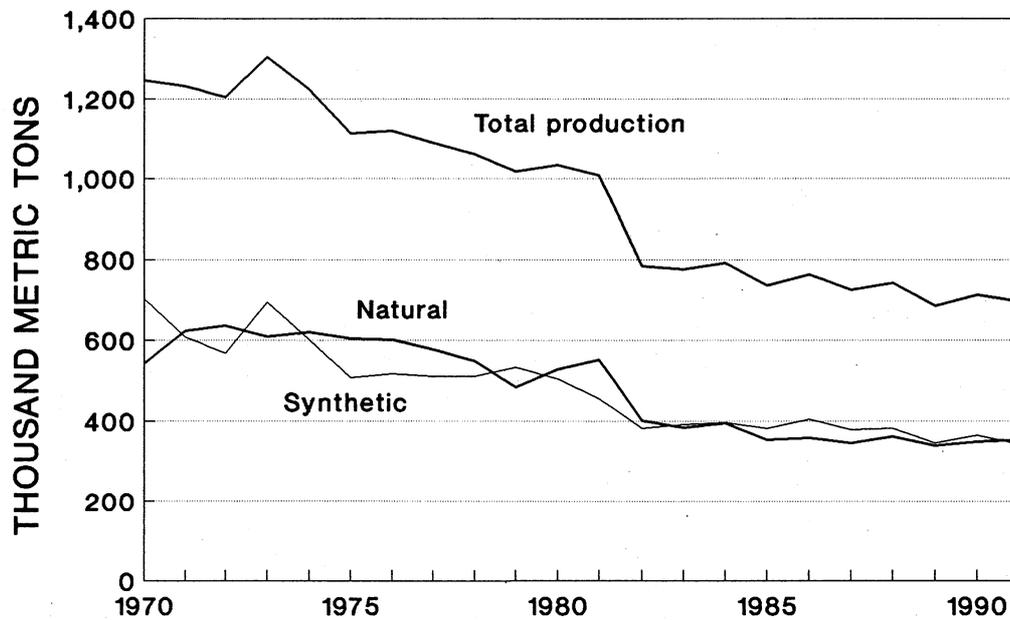
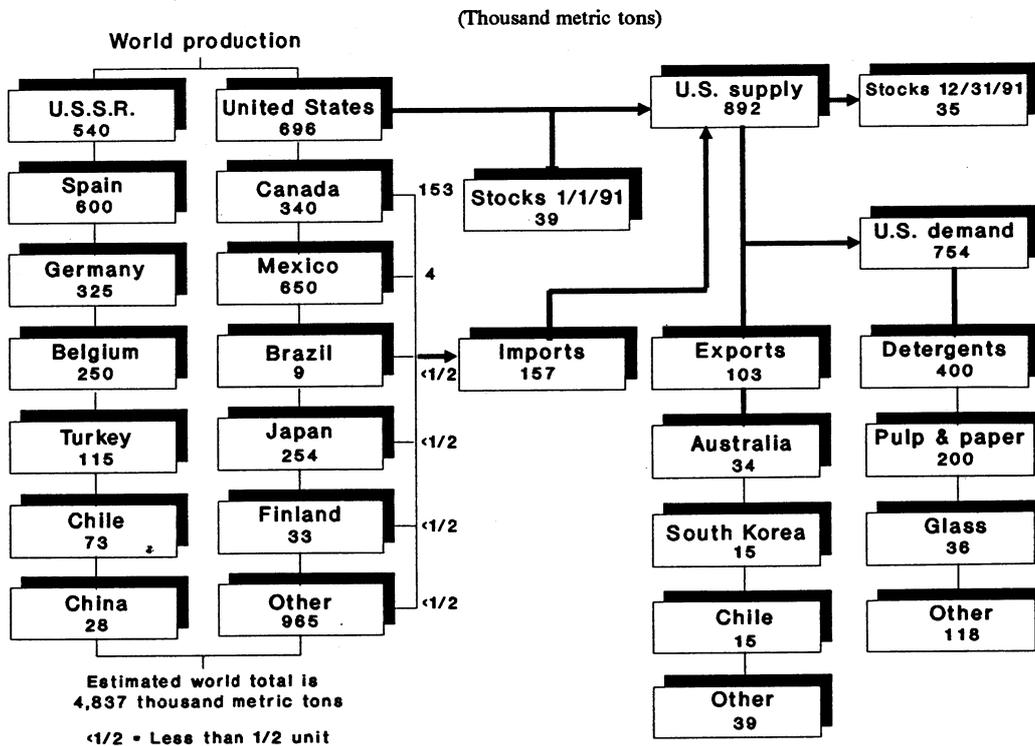
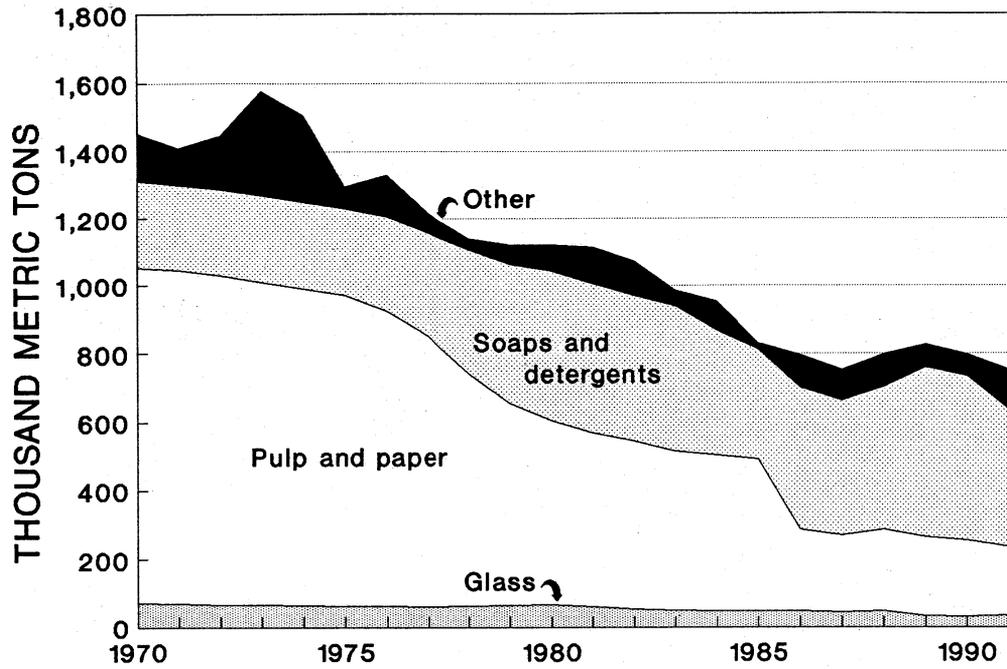


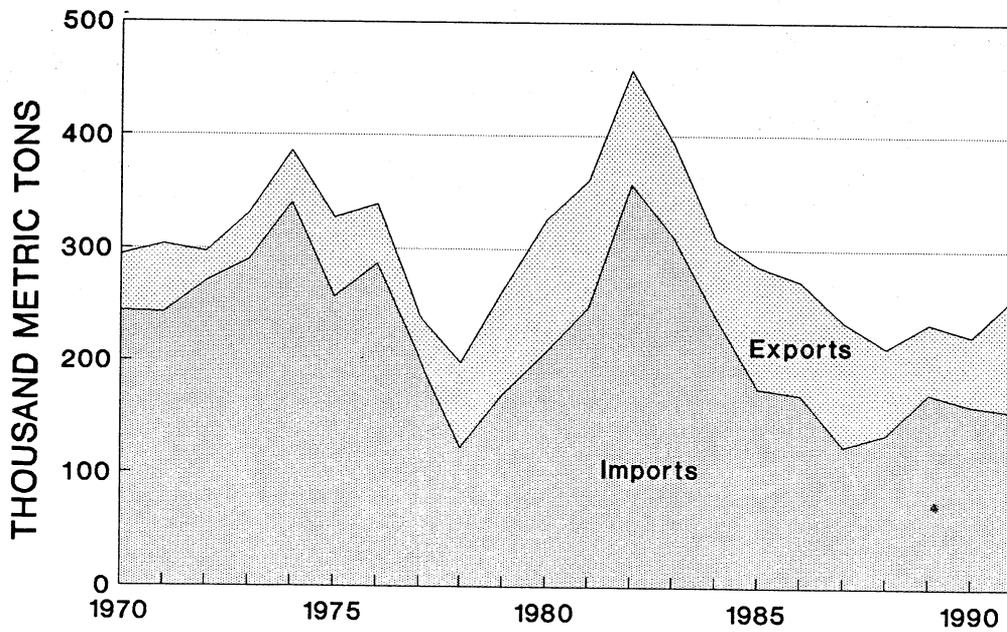
FIGURE 2
SODIUM SULFATE SUPPLY-DEMAND RELATIONSHIPS, 1991



**FIGURE 3
SODIUM SULFATE END USES**



**FIGURE 4
IMPORTS AND EXPORTS OF SODIUM SULFATE**



CRUSHED STONE

By Valentin V. Tepordei

Mr. Tepordei, a geological engineer with more than 20 years of industry experience, has been the crushed stone commodity specialist with the U.S. Bureau of Mines since 1981. Domestic survey data were prepared by the crushed and broken stone survey staff of the Branch of Data Collection and Coordination.

Crushed stone is one of the most accessible natural resources and a major basic raw material used by a wide range of industries from construction to agriculture, chemicals, and complex industrial processes. Despite the relative low value of its basic products, the crushed stone industry is a major contributor to and an indicator of the economic well-being of the Nation.

A total of 1.1 billion short tons of crushed stone was produced for consumption in the United States in 1991, a 9.7% decrease compared with that of 1990. Despite this decrease, the 1991 tonnage represents the fifth consecutive year of crushed stone production of more than 1.1 billion tons. (See table 1.)

About three-quarters of the crushed stone production continued to be limestone and dolomite, followed by granite, traprock, sandstone and quartzite, miscellaneous stone, calcareous marl, shell, marble, volcanic cinder and scoria, and slate, in order of volume. (See table 3.)

Foreign trade of crushed stone remained relatively minor again in 1991. Exports decreased 47.3% to 2.4 million tons, while value decreased 20.3% to \$33 million compared with that of 1990. Imports of crushed stone, including calcium carbonate, increased 15.2% to 5.7 million tons, while the value increased 9.5% to \$38.6 million. Domestic apparent consumption of crushed stone was 1.1 billion tons. (See tables 25 and 26.)

The removal of nonasbestiform Anthophyllite, Tremolite, and Actinolite (AT&A) from the scope of the present Occupational Safety and Health

Administration (OSHA) standards for regulating occupational exposure to asbestos eliminates a major area of concern of the construction aggregates industries. The implementation of the provisions of the amended Federal Water Pollution Control Act of 1977, the Clean Water Act, Section 404, dealing with "wetlands" and the establishment of a "no net loss of wetlands" policy continues to constitute one of the major areas of concern to the construction aggregates industry. The other area of concern is related to the final promulgation of the permissible exposure limit for crystalline silica measured as respirable silica.

DOMESTIC DATA COVERAGE

Domestic production data for crushed stone are developed by the U.S. Bureau of Mines from voluntary surveys of U.S. producers. Full surveys of crushed stone producers are conducted for odd-numbered years only. For even-numbered years, only annual estimates for each State are generated based on information provided by the quarterly sample survey of crushed stone and sand and gravel producers. This survey, implemented by the U.S. Bureau of Mines in 1989, provides production estimates by quarters for each State and the nine geographic regions. The sample surveys canvass most of the large companies in each State, accounting for most of each State's production. The results of this survey are published each quarter in the Quarterly Mineral Industry Survey of Crushed Stone and Sand and Gravel Producers.

Of the 5,039 crushed stone operations surveyed, 3,287 operations with 4,011 quarries were active. Of these, 2,814 operations with 3,456 quarries representing 85.6% of the total number of operations reported to the U.S. Bureau of Mines survey, and their total production represented 92.6% of the total U.S. crushed stone output. The nonrespondent's production was estimated using employment data and/or adjusted prior years' production reports. Of the 2,814 reporting operations, 694 operations with 757 quarries did not report a breakdown by end use. Their production represented 23.2% of the U.S. total and is included in table 14 under "Unspecified uses, actual." The estimated production of 473 operations with 555 quarries represented 7.4% of the U.S. total and is included in table 14 under "Unspecified uses, estimated." A total of 1,290 quarries were either idle or presumed to have been idle in 1991 because no information was available to estimate their production. A total of 462 operations were closed down since 1989, the last year when a full survey of crushed stone producers was conducted.

BACKGROUND

Crushed stone is a term applied to rock that has been broken and/or crushed after quarrying. It is a low-value product characterized by its "place value," a term that describes the importance of the location of the geologic deposit in reference to the market. Stone in its multitude of forms represents a very significant part of the Earth's crust. As one of the most accessible natural

resources, it has been used since the earliest days of our civilization. First used as a tool or weapon, it was then used as a construction material, and later, in its crushed form, as one of the basic raw materials for a wide variety of uses, ranging from agriculture and chemicals to complex industrial processes.

The beginnings of the crushed stone industry are difficult to trace, but it is known that the Greeks, and later the Romans, the first great road builders, used limestone and lime extensively.¹ In the 19th century, the mining of crushed stone was labor intensive. Men with sledge hammers and shovels used their muscles to work the quarries and produce crushed stone that was used mostly for road and railroad construction.² The modern crushed stone industry began in England in about 1815 and expanded rapidly after the invention of the mechanical rock crusher in 1858.³ Today's crushed stone industry is vastly different. It evolved from a labor-intensive to a capital-intensive industry where the work force mostly directs and controls sophisticated and powerful equipment operating in the quarries.

In the United States, railroad ballast was the principal market for the crushed stone industry during the last half of the 19th century. Passage of the Federal Aid Highway Act in 1916 acknowledged the national importance of highways, and subsequent highway construction created a new and significantly larger market. The crushed stone industry grew tremendously, especially in the second half of this century. Production increased from 130 million tons in 1928 to a high of 1.25 billion tons in 1988, mainly owing to rapidly increasing demand for highway, railroad, and other construction work. Today the volume of crushed and broken stone produced is greater than that of any other mineral mined in the United States. The United States is, in general, self-sufficient in crushed stone, producing enough to meet most of the domestic needs. Small quantities of crushed stone, used mostly as construction aggregates, are being imported by water from the Bahamas, Canada, Mexico, and to a

smaller extent Scotland and the United Kingdom.

Most of crushed stone is used for construction purposes, mainly as aggregate with or without a binder. Road base or road surfacing material, macadam, riprap, and railroad ballast are the major uses without a binder. Aggregate for cement and bituminous concrete in highway and road construction and repair and in residential and nonresidential construction are the major uses for aggregates with a binder. Other uses include cement and lime manufacture, agriculture, metallurgical flux, and fillers and extenders.

Although crushed stone resources are widespread and in adequate supply in most parts of the United States, local shortages exist. Land use conflicts and environmental problems associated with rapid urban expansion are major factors contributing to these shortages. Demand pressures, land use regulations, and the cost of meeting environmental and reclamation requirements are factors that will cause a rising price trend. Larger operations with more efficient equipment, more automation, and better planning and design will be the trend of the industry in the future.

Definitions, Grades, and Specifications

Crushed and broken stone is a term applied to rock that has been broken and/or crushed into smaller, irregular fragments or ground to specified particle sizes. Crushed stone is also classified by kind of stone, including limestone, dolomite, marble, shell, granite, traprock, sandstone, quartzite, slate, volcanic cinder and scoria, and miscellaneous stone. The terminology used by the crushed stone industry is not always consistent with mineralogical definitions. Limestone and dolomite are rocks composed, respectively, of the minerals calcite, CaCO_3 , and dolomite, $\text{CaMg}(\text{CO}_3)_2$; however, they are usually called limestone by the industry, and intermediate varieties are seldom distinguished. Some deposits of limestone consist chiefly of the mineral aragonite, which has the same

composition as calcite, but has a different crystal structure. Marble may include any calcareous rock that will accept a polish. Marl is calcitic and contains varying amounts of shale or clay. Granite includes the coarser grained igneous rocks such as true granite and syenite. Gneisses, although metamorphic rocks, are usually included with granite. Quartzite is a well cemented sandstone that is indurated to the extent that, when fractured, it breaks across the grain. Traprock includes all dense, dark, and fine-grained igneous rocks such as basalt, diabase, and gabbro.

Crushed stone in its different rock types and particle sizes is used in a wide variety of applications in many industries, including construction, chemical, metallurgical, and agriculture. For the purpose of collecting and disseminating production information, the U.S. Bureau of Mines generally accepts the rock type classification and the principal end uses and their definitions as reported by the crushed stone producers.

Specifications for crushed stone are numerous because of the large number and the variety of uses, the diversity of stone types, and the variations in physical and chemical requirements for different uses. Various national specifications and tests exist for crushed stone products, but the most active organizations in preparing and reviewing them are the American Society for Testing and Materials (ASTM)⁴ and American Association of State Highway and Transportation Officials (AASHTO). For construction aggregates, these are regarded by industry as guide or reference specifications. State specifications are often much more stringent and vary from State to State. The most common specifications and tests relate primarily to gradation, but soundness, shape, abrasion resistance, porosity, chemical compatibility, and content of soft particles are also important.⁵ Specifications for construction aggregates are written by commercial users; government agencies, including Federal, State, county, and city construction and highway departments; and the ASTM. Problems arise for the producers of construction aggregates

when their product is sold or used in several different cities, counties, or States, many of which may have different specifications. Some progress is being made toward the standardization of aggregate sizes for similar requirements. A need exists for a more active interchange of data and experience among aggregate consumers and producers.

Specifications for limestone used in portland cement manufacture require a content of more than 75% calcium carbonate (CaCO_3) and less than 3% magnesium carbonate (MgCO_3). For white portland cement, the iron content of the raw materials should be very low, less than 0.01%. Because raw materials are finely ground for processing, chert nodules or coarse quartz grains are undesirable. Limestone for lime manufacture should contain more than 90% calcium carbonate, often more than 97% or 98%, less than 5% magnesium carbonate, and less than 3% of other impurities. For lime produced in vertical kilns, 5- to 8-inch stone is recommended, while in rotary kilns 3/8- to 2 1/2-inch stone may be used. Limestone and dolomite should be sufficiently hard so as not to decrepitate when heated. High-magnesium lime made from dolomite should contain more than 40% magnesium carbonate.

Specifications for the use of limestone or dolomite as fluxstone vary with the pyrometallurgical process, the kind of ore processed, and the final use of the slag; silica content should not exceed 2% to 5%, magnesia content should be less than 4% to 15%, and sulfur less than 0.1%. Size specifications also vary and include ranges from 1 to 4 inches, 2 to 4 inches, and 3 to 6 inches. The limestone or dolomite used for glassmaking should contain at least 98% CaCO_3 or MgCO_3 , respectively, and less than 0.05% to 0.02% iron oxide. Size specifications vary with the manufacturer and the kind of glass being produced, but uniformity is a major requirement; usually 100% of the material should pass a No. 10 sieve (2 millimeters) and 96% to 100% should be retained on a No. 100 sieve (0.15 millimeters).

Requirements for agricultural limestone are not very rigid and depend on the specific use: as direct application to soil, as filler and conditioner for fertilizers, in animal mineral feeds, or as poultry grit. In all of these applications, CaCO_3 or MgCO_3 equivalent or content is of major significance. Many individualized specifications exist for a wide variety of industrial applications, mostly pulverized limestone for rock dusting, or as asphalt, plastic, rubber, paper, or paint fillers or extenders.⁶

Products for Trade and Industry

The ultimate use of crushed stone determines the specification for particle size and gradation, shape, rock type, and chemical composition. Crushed stone can be used without any binder, for a variety of construction or industrial applications, or it may be mixed with a matrix binding material such as bituminous or portland cement. The most common use of crushed stone for construction purposes is as aggregate without a binder, including road base or road surfacing material, macadam, riprap, railroad ballast, filter stone, etc. The second largest use of crushed stone is as aggregate for cement and bituminous concrete in a variety of forms and applications in residential and nonresidential construction, highway and road construction and repair, airports, dams, sewers, and foundations. Sized crushed stone is used to make asphaltic concrete aggregate and road bases. Broken surfaces adhere to the hot asphaltic mixture better than rounded surfaces do and provide interlocking surfaces that tend to strengthen the asphaltic concrete. Broken particles pack better and tend to move less under load than rounded particles do and, therefore, make better road bases for highway and road construction. This is essential because bases and asphaltic concrete tend to flow when placed under great or long duration stresses. Other uses include limestone for cement and lime manufacturing and as agricultural limestone used as direct application to soil, as filler and conditioner for fertilizers, in animal mineral feeds, or as

poultry grit. Smaller amounts of crushed stone are used for a wide variety of applications ranging from metallurgical fluxing of antimony, copper, iron, lead, and zinc to the manufacture of glass, ceramic pottery, paper, and as fillers and extenders in asphalt, paint, rubber, and plastics.

A growing amount of limestone is being used in the removal of sulfur oxides from stack gases, primarily from coal burning electric generating stations, and for mine dusting to enhance mine safety by reducing the explosion risk of highly combustible coal dust.

Industry Structure

Because of the low unit value, crushed stone is usually produced near the point of use; therefore, the industry is concentrated mostly in or nearby large, rapidly expanding urban areas. Crushed stone is produced in every State except Delaware, with more than 75% of the national total coming from two major geographic regions, the South and Midwest. The largest quarries tend to be concentrated in the States with the largest populations and largest productions of crushed stone.⁷

Although limestone is produced in all States except Alaska, Delaware, Louisiana, New Hampshire, and North Dakota, the major producing States are east of the Rockies. Crushed marble is produced mostly in the eastern part of the United States in Alabama, Georgia, and Pennsylvania. Crushed granite is produced primarily in Appalachia, with Georgia, North Carolina, South Carolina, and Virginia being the largest producing States. Crushed traprock is produced mainly in the northeast and the Pacific Coast States, with California, Connecticut, Massachusetts, New Jersey, Oregon, and Washington the largest producing States. Crushed sandstone and quartzite are produced in 27 States led by Arkansas, California, and Pennsylvania. Most crushed slate is produced in the Eastern part of the United States, mainly in Arkansas, Georgia, and Virginia. Shell, primarily oyster residue, is produced by dredging along the Gulf

Coast. Volcanic cinder is produced in the West, mainly in Arizona, California, and New Mexico.

On the basis of tonnage, the crushed stone industry is the largest nonfuel mineral industry in the United States. The industry is widespread and has a large variation in operation size, kind of stone, and size of material produced. The individual companies range in size from small, independent producers with one quarry to large, diversified corporations with 50 or more crushed stone operations.

In 1991, 1,597 companies produced crushed stone from 3,287 operations with 4,011 active quarries. Individual crushed stone quarries range in size from those producing between 1 and 11 million tons annually to those reporting less than 50,000 tons per year. However, most of the tonnage comes from large operations. In 1991, for example, 53 operations each reporting production of more than 2 million tons per year represented only 1.7% of the total number of operations, but accounted for 17.4% of total crushed stone production. (See table 8.) The large operations are owned or operated by a small number of companies. In 1991, the combined production of the top 10 producers operating 507 quarries accounted for 30% of the total output of crushed stone in the United States.

The 10 leading producers were Vulcan Materials Co., Beazer USA Inc./Hanson PLC, Martin Marietta Aggregates, Lafarge Construction Materials, Dravo Basic Materials Co., CSR America, Inc., Material Services Corp., Florida Rock Industries Inc., Rogers Group Inc., and Lone Star Industries Inc.

In the past several years, significant changes in the structure of the crushed stone industry have occurred, caused primarily by mergers and acquisitions. An established and well managed company with significant reserves in the ground becomes a potential target of larger companies trying to lock up sufficient reserves or expand into the aggregate business. Some of the recent acquisitions were made by foreign companies or were associated with the influx of foreign capital. Two of the top

five crushed stone-producing companies in 1989 are subsidiaries of foreign companies.

The United States is the largest producer of crushed and broken stone among the market economy countries. Other major producing countries are Australia, Canada, the Federal Republic of Germany, France, Japan, and the United Kingdom. Some information about the production of crushed stone in foreign countries may be found in the U.S. Bureau of Mines Minerals Yearbook Volume III, Area Reports: International. For nonreporting countries, estimates of crushed stone outputs can be based on indirect sources such as the level of cement consumption.

Geology-Resources

Bedrock deposits are classified on the basis of their origin into sedimentary, igneous, and metamorphic rocks. Sedimentary rocks were produced from the consolidation of loose sediments through chemical or mechanical sedimentation. Limestone, which is primarily calcium carbonate (CaCO_3), and dolomite, which is calcium-magnesium carbonate ($\text{CaMg}(\text{CO}_3)_2$), are the most common sedimentary rocks produced through chemical or biochemical sedimentation. Limestone and dolomite formations are widespread in the United States, with most of the deposits being of Paleozoic age, with a few of Mesozoic and Tertiary age. Most States have adequate reserves for use in construction and other applications that do not require chemically pure stone.⁸ High-calcium limestone and high-purity dolomite make up only a small fraction of all limestone and dolomite formations, and they occur in restricted areas, mostly in the eastern part of the United States, with some formations in the Western States as well.⁹ High-purity dolomite deposits are more limited in occurrence than the high-calcium limestone. Of the clastic sedimentary rocks that are produced through mechanical sedimentation, only sandstones, rocks consisting predominantly of cemented sand-size

particles, are, to a limited extent, used as crushed stone.

Igneous rocks, rocks that solidify from molten volcanic magma, are classified as intrusive and extrusive rocks. Intrusive or plutonic rocks are those that were formed deep beneath the ground surface, are coarse grained, and include granite, diorite, and gabbro as rock types. Extrusive or volcanic rocks are igneous rocks that were formed from molten volcanic magma at the Earth's surface, are fine grained, and include andesite, rhyolite, and basalt. Plutonic and volcanic rocks are further subdivided on the basis of mineralogy in light-colored igneous rocks with high-silica content that include granite, diorite, rhyolite, and andesite, and dark-colored igneous rocks low in silica content that include gabbro, diabase, and basalt, commonly called traprock. Granite and traprock are the most common igneous rock types used as crushed stone. Granite occurs primarily in the eastern part of the United States from Maine to Georgia, along the Appalachian Range where major producing States are located. It also occurs in Arkansas, Minnesota, Missouri, Oklahoma, Texas, and Wisconsin and in all Western States except Utah. Most of the traprock occurs in California, Hawaii, Idaho, Oregon, and Washington in the West; in Connecticut, Maryland, Massachusetts, New Jersey, New York, North Carolina, Pennsylvania, and Virginia in the East; and to a smaller extent in Minnesota and Texas.

Metamorphic rocks are formed from preexisting rocks through mineralogical, chemical, and structural changes produced by high heat and pressure. The metamorphic rocks include gneisses, marbles, quartzite, slates, and schists. Marble, quartzite, and slate are the major types of metamorphic rocks used to some extent as crushed stone. Marble occurs primarily in Alabama, Georgia, New York, Vermont, and Virginia in the East and in California and Texas in the West.

A comprehensive report showing geologic occurrences of potential sources of crushed stone and sand and gravel of the conterminous United States for use as

natural aggregates was published by the U.S. Geological Survey.¹⁰

On the basis of geologic evidence, stone resources of the United States and the world are sufficient to meet demands, although not always precisely at the locations where needed. Reserves, which are measurable amounts of crushed stone that can be produced profitably with current technology under existing economic and political conditions, are controlled mostly by land use and/or environmental constraints. The actual volume of stone available is so vast as to preclude the necessity of measurement on a large scale. The local shortages that occasionally exist are caused less by a lack of stone than by urban encroachment or zoning regulations that force closure of operating quarries or prevent the development of new ones.

Technology

Major technological developments have been instrumental in maintaining adequate production at relatively stable real costs in the crushed stone industry. Equipment manufacturers usually conduct most of the research related to improvements in the mining and processing of crushed stone operations. Larger, more efficient equipment is being developed and improved constantly. The use of computerized control systems in plant operation and quality control has increased significantly in recent years. Automatic controls, along with monitoring by closed-circuit television coordinated with automated counting and recording and radio communications systems, have been installed in many of the larger and newer operations. Automated plants have significantly improved operating efficiency and produce the optimal product mixture to fit market requirements at lower cost.

As part of the national drive to reduce air pollution, significant progress is being made toward the desulfurization of stack gases resulting from coal burning electric generating stations and some industrial installations.¹¹ Limestone and lime are used as chemically reactive agents in most of the dry or wet scrubbing

processes as well as in the treatment of acidified waters, specifically lakes and streams.

Exploration.—A large number of geologic formations that have economic potential as a source of crushed stone have been mapped and described in the literature over the years. Consequently, detailed exploration and development work for any new crushed stone operation will most probably be done on one of these formations. However, in the event that a new stone deposit is discovered, more exploration and evaluation work would be required before development. Preliminary examination can establish the extent and nature of the deposit. This is followed by a detailed exploration program aimed at obtaining reasonably accurate information about the quality of the available material, including the kind of stone, its chemical composition and degree of cementation, and the degree of uniformity throughout the deposit. Also, the nature and the amount of waste material and the economic feasibility of its removal, processing, and marketing must be studied. In most cases, an environmental impact study is required by local or State agencies.

If the raw material cost and quality are proven to be adequate and sufficient reserves are demonstrated, the development stage of the operation can be started. Economic feasibility and marketing studies include: analysis of the availability of power and water supply; mining and processing costs and requirements; the condition of nearby roads and highways and the proximity of rail haulage; the cost of compliance with local, State, and Federal regulations; and the proximity and density of local population, as well as its attitude toward such a project.

Mining.—Most crushed and broken stone is mined from open quarries; however, in many areas, factors favoring large-scale production by underground mining are becoming more frequent and more prominent.

Surface mining equipment varies with the kind of stone mined, the production capacity needed, the size and shape of the deposit, estimated life of the operation, location of the deposit with respect to urban centers, and other important factors. Ordinarily, drilling is done with tricone rotary drills, long-hole percussion drills, and churn drills. Blasting in smaller operations may still be done with dynamite, but in most medium- to large-size operations ammonium nitrate-fuel oil mixtures (AN-FO), which are much lower in cost, are used.

Underground operations are becoming more common, especially for limestone mining in the central and eastern parts of the United States, as the advantages of such operations are increasingly recognized by the producers. By operating underground, a variety of problems usually connected with surface mining such as environmental impacts and community acceptance are significantly reduced. Underground room-and-pillar mines can be operated on a year-round basis, do not require extensive removal of overburden, and produce a minimum of environmental disturbance. The need for less surface space is also an important factor in areas of high land costs. Subsidence has not been a problem in areas mined, and the conventional practice has been to leave 12% to 15% of pillar areas and 6 to 8 feet of stone in the mined roof. A specific advantage of underground quarries is the creation of valuable storage facilities. In many cases, the value of the sale or rental of the storage space may exceed the value of the stone mine. Thus, the incentives for producing stone from underground mines can be enhanced by the economic advantages of subsequent use of the excavated areas.

Loading and hauling equipment has grown larger as increased demand for stone has made higher production capacities necessary. Track-mounted equipment is still used extensively, but hydraulic, tire-mounted hauling equipment is predominant.

Processing.—Processing plants have become larger and more efficient, in part

because of an increase in the use of computerized control systems. Programmable controllers and/or computers are viewed today as valuable tools that improve operating efficiency and product quality. Primary crushing is often done at or near the pit, usually by jaw or gyratory crushers, but impact and other special types of crushers are also used for nonabrasive stone or stone that tends to clog conventional crushers. The cost effectiveness of permanent crushing installations can be limited because the raw material moves away from the primary stage. It becomes increasingly expensive to haul material from the production face to the crushing plant. Improved crusher technology and increased capacity toward greater equipment mobility are accelerating the use of in-pit movable primary crushers. There is an increased interest in the use of portable crushers ranging in size from 500 tons per hour up to 5,000 tons per hour. For secondary crushing, a variety of comminution equipment is used, depending on plant size, rock type, and kind of material being produced. Cone crushers and gyratory crushers are the most common types used, but impact crushers, including hammer mills, and roll crushers are often used. Belt conveyors are being used extensively to haul material within the quarry because they provide continuous operation, low maintenance costs, low work force requirements, and reduced noise levels. Conveying systems are often associated with in-pit crushers and consist of several portable units and a stationary field conveyor. The portable conveyors, usually in 100- to 200-foot lengths make the connection between the portable crusher and the field conveyor and provide a good range of motion. The increased use of conveyors reduces significantly the use of haul trucks in quarries.

Screening is the single most important part of the processing cycle of crushed stone particles. A wide variety of screen types exists, and their selection is a function of the material processed as well as the final product required. Inclined vibratory screens are most commonly

used in stationary installations, while horizontal screens are used extensively in portable plants. For screening large sizes of crushed stone, grizzly bars, rod decks, and heavy punched steel or plastic plates are used; for smaller sizes, woven wire, welded wire cloth, rubber, or plastic screens are used.

Processed crushed stone is usually stored in open areas except for relatively small quantities that go to the loadout bins. In the more efficient plants, the crushed stone is transported from the storage piles on belt conveyors through tunnels installed under the piles, thus facilitating the blending of any desired mixture of sizes from different piles.

Recycling.—As the Nation moves into an age of increased environmental consciousness, recycling of old concrete and asphalt, used mostly in pavements, is increasing. Local scarcity or high cost of construction aggregates in some areas as well as waste disposal problems are making recycling more attractive economically. In some States, limited recycling, especially in road construction, is either encouraged or required by law. The best utilization for recycled cement concrete is as road base material, because the matrix of concrete cannot be converted back to cement, and also because of the lower strength of concrete compared with that of natural aggregates. Sound crushed concrete can make good coarse aggregate, but the fines produced in crushing the concrete have a higher absorption, are more friable, and will require a higher amount of asphalt in asphaltic concrete and a higher amount of mixing water in portland cement.¹²

The amount of asphalt roads recycled is significantly larger than that of concrete roads, mainly because asphalt can be rejuvenated with oil additives and used in pavements, significantly reducing the cost of the finished road. Experience has shown that about 35% of crushed asphalt pavement can be recycled into new asphalt mixtures. Proper testing under engineering supervision in all construction projects using recycled materials as aggregates should be

performed to ensure that the technical specifications are met.

Byproducts and Coproducts

Clay of good quality is sometimes encountered in limestone overburden and is mined as a coproduct. Gypsum is often encountered beneath beds of limestone and is mined as a coproduct. Amphibolite rock often occurs as formations paralleling spodumene-bearing pegmatitic dikes and is mined concurrently with these, notably in North Carolina. This coproduct of lithium mining is marketed primarily as roadstone. Stone is also mined in conjunction with many metallic ores and nonmetallic minerals, but seldom does a market exist for it.

Economic Factors

Crushed stone is a high-volume, low-value commodity. The industry is highly competitive and is characterized by thousands of operations serving local or regional markets, largely because stone is an abundant mineral. Production costs are determined mainly by the cost of labor, equipment, energy, and water, in addition to the costs of compliance with environmental and safety regulations. These costs vary depending on geographic location, the nature of the deposit, and the number and type of products produced. Despite having one of the lowest average per ton values of all mineral commodities, the constant dollar price of crushed stone has changed relatively little over the past 20 years. As a result of rising costs of labor, energy, and mining and processing equipment, the average unit price of crushed stone increased from \$1.58 per ton, f.o.b. plant, in 1970 to \$4.70 in 1991. However, the unit price in constant 1987 dollars fluctuated between \$3.37 and \$3.90 per ton, while the unit price in constant 1970 dollars fluctuated between \$1.41 and \$1.63 per ton for the same period. (See table 2 and figure 2.) Increased productivity achieved through increased use of automation and more efficient equipment was mainly

responsible for maintaining the prices at this level.

The delivered price of the product, in addition to quality, is a particularly important element in any major transaction because of the low unit value of crushed stone, and therefore, producers that are closest to markets have a significant advantage. Sophisticated equipment backed by technical knowledge combined with solid sales expertise are becoming very important. For this reason, large companies are better able to compete in the crushed stone business, especially when there is a need for a wide variety of products. Smaller, less efficient operations become less economical as operating costs, as well as costs associated with meeting various Federal, State, and local regulations, continue to increase. The only alternatives these producers have are to supply local markets with a limited number of products. The gradual trend toward larger operations has continued, mostly because the stone industry is capital intensive, and it is becoming less economical to operate small quarries. The viability of small operations is dependent on the demand in the local markets, mining costs, and the degree of processing required to supply the final product.

A 5% depletion allowance based on gross income is allowed for crushed stone used in construction, including aggregates. The depletion allowance for chemical and metallurgical crushed stone is 14%.

Operating Factors

Many States, counties, and cities in the United States have zoning laws, and land within each governmental unit is usually zoned to indicate acceptable land uses. If mining is permitted in a zone and a crushed stone company owns or leases land within that zone, the company may apply for a use permit or its equivalent to begin an operation. If the parcels to be quarried are on lands under both city and county jurisdiction, permits usually must be obtained from each. An acceptable reclamation plan that meets the guidelines

or regulations of the appropriate governmental agency must also be approved. Environmental concerns such as noise, dust, beautification, and storage of wastes must be accounted for in a manner satisfactory to the governmental entity involved. Wastewater discharge requirements must be planned for and met. If the deposit to be worked is on land controlled by a State or Federal agency, that agency's requirements must also be satisfied.

In most States, permits for crushed stone operations require an Environmental Impact Report (EIR) or Environment Impact Statement (EIS). A reclamation plan and a use permit application may also be required, with considerable overlap of subject matter with the EIS. A complete EIS may cover all the problem areas at once and facilitate acceptance.

Environmental Requirements.—Many of the environmental problems facing crushed stone producers arise because a great number of stone quarries and processing plants are in suburban areas near the major crushed stone markets. Major environmental considerations that must be dealt with in mining and processing of crushed stone are emission of particulate matter into the air, discharge of processing water, noise abatement, and employee and public health and safety. Air pollution constitutes a major problem in processing plants, especially in the drying and packaging stages of fine particle products such as limestone used as fillers or extenders. Both wet and dry methods of dust control are used. The most important water pollutant is clay in suspension that results from washing and screening crushed stone. Because of the large quantities of water used to process stone and the need for compliance with often stringent regulations, the treatment of discharge water by crushed stone producers is becoming a necessity that may require sophisticated and expensive processing methods. Significant progress has been made in reducing noise pollution both inside and outside of the quarries, including noise and vibration produced by

blasting and movement of heavy trucks. Therefore, the industry must be concerned first about any practices that can affect the community environment. An effective effort must be made to reduce noise, air, and water pollution and to improve the overall appearance of the operating mine, processing plant, and transportation facilities. Second, the industry and community must recognize the time and costs required to protect the environment and the importance of agreeing on fair and realistic environmental standards. Because crushed stone is a local industry, the effect of supply deficiencies and cost of material will affect the local community first. Undue delay and unreasonably high cost can strongly affect the movement of crushed stone into the marketplace. Also, stringent controls by the local governments that prevent permits being issued to operators can have adverse economic effects on the communities around them. These conditions can make it difficult to assess the timing and even the possibility of plants going on-stream and can therefore affect the supply of crushed stone into the marketplace.

Although much progress is being made through premining planning, the crushed stone industry continues to have problems with environmental controls, land use conflicts, and reclamation practices. Many of these problems are acute because extraction areas and plants must be reasonably near to consumers who are largely in metropolitan areas.

Transportation.—Transportation is a major factor in the delivered price of crushed stone. The cost of moving crushed stone from the plant to the market often equals or exceeds the sales price of the product at the plant. Because of the high cost of transportation and the large quantities of bulk material that have to be shipped, crushed stone is usually marketed locally. The high cost of transportation is responsible for the wide dispersion of quarries around the country, usually near highly populated areas.

However, increasing land values combined with local environmental concerns are moving crushed stone

quarries farther from the end-use locations, increasing the price of delivered material. Economies of scale, which might be realized if fewer, larger operations served larger marketing areas, would probably not offset the increased transportation costs.

Truck haulage is the main form of transportation used in the crushed stone industry, despite the fact that it is the most expensive mode of transportation on a cost-per-ton/per-mile basis. Many producers have their own truck fleet and deliver their own raw materials and products. A significant and increasing amount of crushed stone, however, is being hauled by independent truckers because of the cost of maintaining a truck fleet, particularly when the market is highly variable. Rail and water transportation combined account for about 8% of total crushed stone shipments. In recent years, an increased amount of crushed stone is being shipped into the United States by water from Bermuda, Canada, Mexico, and United Kingdom, using large ocean-going vessels. Some of these are self-unloading vessels.

ANNUAL REVIEW

In 1991, a total of 1.1 billion short tons of crushed stone was produced for consumption in the United States, a 9.7% decrease compared with that of 1990. Despite this decrease, the 1991 tonnage represents the fifth consecutive year of crushed stone production more than 1.1 billion tons.

Legislation

On December 18, 1991, the Intermodal Surface Transportation and Infrastructure Act of 1991 became Public Law 102-240. The new law authorized \$151 billion to be spent in the next 6 years on transportation projects, \$119.5 billion on highway work, and \$32.5 billion on mass transit. The new law defines a new national highway system that combines interstate routes with selected State routes, creates a Surface Transportation Program that replaces categorical grants to the States, and restructures the

Federal-Aid Highway Program giving State legislatures and Metropolitan Planning Organizations more flexibility in choosing projects and transferring funds between spending categories.

On June 8, 1992, OSHA announced that it was amending its standards governing the "Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite (AT&A)"¹³ by removing nonasbestiform AT&T from the scope of the present standards affecting the general industries, including the construction industries. OSHA has determined that substantial evidence is lacking to conclude that AT&T present the same type or magnitude of health effect as asbestos or that employees would be at significant risk because nonasbestiform AT&T were not regulated in the asbestos standards. The latest administrative stay of enforcement of the revised standards was also removed by OSHA effective May 29, 1992.

Issues

The implementation of the provisions of the amended Federal Water Pollution Control Act of 1977, the Clean Water Act, Section 404, dealing with "wetlands" and the establishment of a "no net loss of wetlands" policy constitutes one of the major areas of concern to the crushed stone industry. There is a significant amount of uncertainty regarding the process of designating some lands as wetlands and whether the current exemptions to the Clean Water Act, Section 404, permit program will be maintained in the future. Several bills were introduced in the 102d U.S. Congress to replace the current Section 404 of the Federal Water Pollution Control Act. The new proposed bills plan to provide a concise and structured program for the delineation of wetlands based on their functions and values and will balance the need for effective protection of the Nation's important wetlands with the need for essential community growth and the constitutional rights of landowners.

The removal of nonasbestiform AT&T from the scope of the present OSHA

standards for regulating occupational exposure to asbestos in general industries, including the construction industries, eliminates a major area of concern for the construction aggregates industries. Based on the entire rulemaking record, OSHA has determined that substantial evidence is lacking to conclude that nonasbestiform AT&T present the same type or magnitude of health effects as asbestos. OSHA also concluded that substantial evidence does not support a finding that exposed employees would be at significant risk because nonasbestiform AT&T were not regulated in the asbestos standard.

Another issue of concern to the construction aggregates industries is the classification of crystalline silica as a probable human carcinogen by the International Agency for Research on Cancer, an agency of the World Health Organization. OSHA-regulated sites that receive and/or use products containing more than 0.1% crystalline silica must comply with OSHA's Hazard Communication Standard. Both the classification of crystalline silica as a probable human carcinogen and the requirement to quantitatively analyze for crystalline silica at the 0.1% level are controversial.

Production

A total of 1.1 billion short tons of crushed stone was produced for consumption in the United States in 1991, a 9.7% decrease compared with that of 1990. (See table 1.) Of this total, 784 million tons or 71.1% was limestone and dolomite, 164 million tons or 14.9% was granite, and 83 million tons or 7.6% was traprock. The remaining 6.4% was shared, in descending order of quantity, by sandstone and quartzite, miscellaneous stone, calcareous marl, shell, marble, volcanic cinder and scoria, and slate. (See table 3.)

A comparison of the four major geographic regions indicates that in 1991 the South continued to lead the Nation in the production of crushed stone with 498.8 million tons or 45.2% of the total, followed by the Midwest with 335.6

million tons or 30.4%, and the Northeast with 144.5 million tons or 13.1%. Approximately 75% of the total U.S. crushed stone output was produced in two major geographic regions, the South and the Midwest. (See table 4.)

Of the nine geographic regions, the South Atlantic led the Nation in the production of crushed stone with 254 millions tons or 23% of the U.S. total. Next was the East North Central region with 222 or 20.1% of the total, followed by the Middle Atlantic with 124 million tons or 11.3%.

A comparison of the estimated 1990 and reported 1991 production data by regions indicates that the output of crushed stone decreased in all regions except the East North Central, the Pacific, and the Mountain. The largest decreases were recorded in New England, -24.5%; the Middle Atlantic, -21.2%; and the South Atlantic, -17.6%; while the increases were significantly smaller and occurred in the Pacific, 10.7%, and East North Central, 1.6%. Crushed stone was produced in every State except Delaware.

The 10 leading States in the production of crushed stone, in order of volume, were Pennsylvania, Illinois, Texas, Florida, Virginia, Missouri, Ohio, North Carolina, Kentucky, and California. Their combined production represented 49.6% of the national total.

Fewer changes in ownership, acquisitions by domestic or foreign companies, and mergers occurred in the crushed stone industry in 1991 compared with those of the prior years. Martin Marietta Aggregates of Raleigh, NC, acquired in the first half of 1991 a granite quarry operated by Barrow-Gwinnett Co. of Auburn, GA.

Rogers Group, Inc. of Nashville, TN, acquired the assets of Moulton Limestone Co. of Moulton, AL, which operates a limestone quarry in Moulton Alabama. Later in the year, Rogers Group also purchased the assets of Crushed Stone Inc. of Cowan, TN, and Lynchburg Stone Inc. of Lynchburg, TN. The two companies operate quarries in Moore and Franklin Counties of Tennessee.

Vulcan Materials Co. of Birmingham, AL, and its Mexican partner in the

Yucatan Peninsula quarry operation, Grupo ICA of Mexico City, Mexico, acquired in September the construction aggregates operations of Southdown Inc., of Hernando, FL, in Hernando and Polk Counties, Florida. These operations will be supplied with crushed limestone from the Yucatan quarry.

Hanson PLC of London, United Kingdom, an industrial management company operating mostly in the United Kingdom and the United States, acquired in the second half of 1991 C. H. Beazer PLC, of Bath, United Kingdom, the parent company of Beazer USA, Inc. of Dallas, TX. The acquisition followed Beazer's announcement in July of company plans to sell most of its European operations, including real estate and construction contracting operations. Beazer USA is the largest construction sand and gravel- and the second largest crushed stone-producing company in the United States.

Limestone.—The 1991 output of crushed limestone, including some dolomite, decreased 10.4% to 723 million tons valued at \$3.1 billion, compared with the 1989 totals. (See table 3.) In addition to the quarries reporting only limestone, 18 quarries reported producing both limestone and dolomite, without making a distinction between the two kinds of stone. Their production, 10.1 million short tons, was included with the limestone, and therefore, the limestone totals shown in this chapter include an undetermined amount of dolomite, in addition to the dolomite reported separately. Limestone was produced by 950 companies at 2,050 operations with 2,201 quarries in 47 States. Leading States, in order of tonnage, were Texas, Illinois, Florida, Kentucky, and Missouri; these five States accounted for 37% of the total U.S. output. (See table 9.) Leading U.S. producers were, in order of volume, Vulcan Materials Co., Beazer USA, Lafarge Construction Materials, Martin Marietta Aggregates, and CSR Corp. These five companies accounted for about 22.6% of total U.S. output of limestone.

Dolomite.—Production of dolomite increased 23.7% to 61 million tons valued at \$308.6 million, compared with the 1989 reported totals. (See table 3.) This increase is mostly due to better reporting by the producing companies. Crushed dolomite was reportedly produced by 90 companies at 130 operations with 137 quarries in 28 States. An additional undetermined amount of dolomite is included in the total crushed limestone. Leading States in the production of dolomite, in order of tonnage, were Pennsylvania, Illinois, New York, Michigan, and Ohio; these five States accounted for 63% of the total U.S. output. (See table 9.) Leading U.S. producers were Marblehead Lime Co., Asarco Inc., Lone Star Industries, Eastern Industries Inc., and Michigan Minerals Associates; their combined production represented 36% of the total U.S. dolomite production.

Marble.—Production of crushed marble decreased significantly to 3.7 million tons valued at \$83.3 million, mostly owing to changes in reporting the kind of stone produced by some companies. (See table 3.) Crushed marble was produced by 15 companies with 26 operations and 46 quarries in 11 States. Leading States, in order of tonnage, were Alabama and California; these two States accounted for 57.7% of the total U.S. output. (See table 10.) Leading producers of crushed marble, in order of tonnage, were Georgia Marble Co., ECC America, and Calmat of Arizona; their combined production represented 64% of the total U.S. output.

Calcareous Marl.—Output of marl increased 11.4% to 5.7 million tons valued at 13.8 million. (See table 3.) Marl was produced by 14 companies at 15 quarries in 6 States. South Carolina accounted for 57.8% of total U.S. output. (See table 11.) Leading producers, in order of tonnage, were Holnam Inc., Giant Group Ltd., and Medusa Aggregates Co.; their combined production represented 58% of the total U.S. output.

Shell.—Shell is mainly derived from fossil reefs or oyster shell. The output of crushed shell decreased 21% to 5.5 million tons valued at 44.4 million. (See table 3.) The decrease is mostly due to the restrictions imposed on the industry in Louisiana as a result of concerns that shell dredging produces irreversible damage to the environment. Crushed shell was produced by 11 companies from 14 quarries in 6 States. The major producing States were Louisiana and Florida, and the leading producers, in order of tonnage, were Dravo Basic Materials Co., Quality Aggregates Inc., and Sun City Shell, Inc.; their combined production represented 91% of the U.S. output.

Granite.—Compared with that of 1989, the 1991 output of crushed granite decreased 2.5% to 164 million tons valued at \$864 million. (See table 3.) Crushed granite was produced by 157 companies at 334 operations with 492 quarries in 36 States. Leading States, in order of tonnage, were North Carolina, Georgia, Virginia, South Carolina, and California; these five States accounted for 69.5% of the U.S. output. (See table 12.) Leading U.S. producers, in order of tonnage, were Vulcan Materials Co., Martin Marietta Aggregates, Beazer USA, Florida Rock Industries, Inc., and Tarmac America, Inc; their combined production represented 51% of the U.S. total.

Traprock.—Production of crushed traprock decreased 16% to 83.3 million tons valued at 485 million. (See table 3.) Traprock was produced by 242 companies at 561 quarries in 31 States. Leading States, in order of tonnage, were Oregon, Washington, California, Virginia, and New Jersey; these five States accounted for 64.5% of U.S. output. (See table 12.) Leading U.S. producers, in order of tonnage, were Vulcan Materials Co., Syar Industries, Inc., Beazer USA, Luck Stone Corp., and Traprock Industries Inc.; their combined production accounted for 20% of the total U.S. output.

Sandstone and Quartzite.—The combined output of crushed sandstone and quartzite decreased 10.5% to 28.5 million tons valued at 137.7 million. (See table 3.) Crushed sandstone was produced by 110 companies at 132 operations with 208 quarries in 27 States, while crushed quartzite was produced by 26 companies at 26 quarries in 17 States. Leading States in the production of sandstone, in order of tonnage, were Arkansas, Pennsylvania, and South Dakota; their combined production represented 43.1% of the U.S. output. (See table 12.) Leading States in the production of quartzite were California and South Dakota. Leading producers, in order of tonnage, were Arkola Sand and Gravel Co., American Rock and Asphalt Inc., and Latrobe Construction Co. for crushed sandstone and Southdown Inc., Concrete Materials Co., and County Line Quarry Inc. for crushed quartzite. The combined production of the top three producers represented 17% of the total output of crushed sandstone and 58% of the total output of crushed quartzite, respectively.

Slate.—Compared with that of 1989, the 1991 output of crushed slate decreased 27.9% to 1.5 million tons valued at 8.8 million. (See table 3.) Crushed slate was produced by six companies at seven quarries in five States. Most of the crushed slate is produced in North Carolina. Leading producers, in order of tonnage, were Martin Marietta and Lesuer-Richmond Slate Corp.

Volcanic Cinder and Scoria.—Production of volcanic cinder and scoria decreased 43.8% to 2 million tons valued at \$11.5 million. (See table 3.) Volcanic cinder and scoria were produced by 32 companies from 46 operations in 15 States. Leading States, in order of volume, were California, Oregon, and New Mexico; their combined production accounted for 52.7% of the total U.S. output. (See table 13.) Leading producers, in order of tonnage, were Martin Marietta, the U.S.

Forest Service, and Stony Point Rock Quarry Inc; their combined production accounted for 43% of U.S. output.

Miscellaneous Stone.—Output of other kinds of crushed stone decreased 12.1% to 24.7 million tons valued at \$122.7 million. (See table 3.) Miscellaneous stone was produced by 111 companies from 130 operations with 186 quarries in 33 States. Leading States, in order of volume, were Pennsylvania, California, and Arkansas; their combined production accounted for 44.1% of the total U.S. output. (See table 13.) Leading producers, in order of tonnage, were Evered Bardon PLC, Haines & Kibblehouse, Inc., and Better Materials Corp.

Consumption and Uses

Crushed stone production reported to the U.S. Bureau of Mines is actually material that was either sold or used by producers. Stockpiled production is not reported. Therefore, the "sold or used" tonnage represents the amount of production released for domestic consumption or export in a given year. Because some of the crushed stone producers did not report a breakdown by end use, their total production is reported under "Other unspecified uses, actual." The estimated production of nonrespondents is reported under "Other unspecified uses, estimated."

In 1991, U.S. consumption of crushed stone was 1.1 billion tons valued at 5.2 billion, a 9.7% decrease from the estimated consumption of 1990 and a 9.1% decrease from the reported consumption of 1989. About 55.9% of this tonnage was used as construction aggregates, mostly for highway and road construction and maintenance; 10% for chemical and metallurgical uses, including cement and lime manufacture; 2% for agricultural purposes; 1% for special uses and products; and 31% for other unspecified uses. (See table 15.) If the above percentages are calculated without the "unspecified uses," which totaled 340 million tons in 1991, then

about 81% of the reported tonnage was used as construction aggregates, mostly for highway and road construction and maintenance; 15% for chemical and metallurgical uses, including cement and lime manufacture; 3% for agricultural purposes; and 1% for special uses and products. The second breakdown is more representative of the actual distribution of crushed stone uses and should be utilized when analyzing the industry. It is recommended that in any such analysis, the quantities and values included in "Other unspecified uses" be distributed among the reported uses being analyzed, based on the following calculation: the percentage for each reported use should be calculated as a percentage of the U.S. total minus "Other unspecified uses"; the resulting percentages then should be applied to "Other unspecified uses" and the resulting quantities and values added to the reported uses published in the table. The same procedure should be used when calculating consumption by each kind of stone.

Limestone.—Of the 723 million tons of crushed limestone consumed, 219 million tons or 30.3% was reported as "Other unspecified uses." Of the remaining 504 million tons of crushed limestone reported by uses by the producers, 74.2% was used as construction aggregates, 19.3% for cement and lime manufacturing, 3.7% for agricultural purposes, 1.4% for chemical and metallurgical uses, and 1.2% for special uses and products. (See table 17.)

Dolomite.—Of the 61 million tons of crushed dolomite consumed, 7.7 million tons or 12.7% was reported as "Other unspecified uses." Of the remaining 53.3 million tons of crushed dolomite reported by uses by the producers, 87% was used as construction aggregates, 4.9% for agricultural purposes, 2.8% for dead-burned dolomite, 2% for special uses, and 1.3% for lime manufacturing. An additional undefined amount of dolomite consumed in a variety of used, mostly construction aggregates, is reported with the limestone. (See table 17.)

Marble.—Of the 3.7 million tons of crushed marble consumed, 1.9 million tons or 50.6% was reported as "Other unspecified uses." Of the remaining 1.8 million tons of crushed marble reported by uses by the producers, 10.7% was used as construction aggregates, 31.2% for cement manufacture, and 60.7% for miscellaneous uses, including fillers and extenders. (See table 18.)

Calcareous Marl.—Of the 5.7 million tons of crushed calcareous marl consumed, 1.7 million tons or 29.2% was reported as "Other unspecified uses." Of the remaining 4 million tons of crushed marl reported by uses by the producers, 79.7% was used for cement manufacturing, 17.2% as construction aggregates, and 3.2% for agricultural purposes.

Shell.—Of the 5.5 million tons of crushed shell consumed, 4.2 million tons or 76.2% was reported as "Other unspecified uses." Of the remaining 1.3 million tons of crushed shell reported by uses by the producers, 98.9% was used as construction aggregates.

Granite.—Of the 164 million tons of crushed granite consumed, 55.4 million tons or 33.7% was reported as "Other unspecified uses." Most of the remaining 109 million tons of crushed granite reported by uses by the producers was used as construction aggregates. (See table 19.)

Traprock.—Of the 83 million tons of crushed traprock consumed, 24.2 million tons or 29.1% was reported as "Other unspecified uses." Most of the remaining 59 million tons of crushed traprock reported by uses by the producers was used as construction aggregates. (See table 19.)

Sandstone and Quartzite.—Of the 22 million tons of crushed sandstone consumed, 8.9 million tons or 40.9% was reported as "Other unspecified uses." Of the remaining 13 million tons of crushed sandstone reported by uses by the

producers, 94.3% was used as construction aggregates and 5.7% for chemical and metallurgical uses. (See table 20.)

Of the 6.6 million tons of crushed quartzite consumed, 1.6 million tons or 24.4% was reported as "Other unspecified uses." Of the remaining 5 million tons of crushed quartzite reported by uses by the producers, 50.1% was used as construction aggregates and 49.9% for chemical and metallurgical uses.

Volcanic Cinder and Scoria.—Of the 2 million tons of volcanic cinder and scoria consumed, 600,000 tons or 29.7% was reported as "Other unspecified uses." Of the remaining 1.4 million tons of crushed volcanic cinder and scoria reported by uses by the producers, 99.3% was used as construction aggregates. (See table 21.)

Miscellaneous Stone.—Of the 37 million tons of miscellaneous crushed stone consumed, 21.3 million tons or 57% was reported as "Other unspecified uses." Of the remaining 16 million tons reported by uses by the producers, 76.4% was used as construction aggregates and 20% was used for cement manufacturing. (See table 22.)

Prices

The 1991 average unit price of crushed stone increased 7.1% to \$4.70, compared with that of 1989, the last time when an annual survey of the crushed stone producers was conducted. By kind of stone, the average unit prices showed increases of 16.7% for miscellaneous stone, 15% for dolomite, 10% for traprock, 7.2% for limestone, 6.2% for calcareous marl, 3.6% for sandstone and quartzite, 2.3% for granite, and 1.6% for volcanic cinder. At the same time, the average unit price for slate decreased 5.3%. Very large increases were recorded in the average unit price for marble, 97.7%, due to some specialized products produced in 1991, and shell, 61.4%, mostly due to the restrictions

imposed on the production of shell in Louisiana.

As a result of rising costs of labor, energy, and mining and processing equipment, the average unit value of crushed stone increased over the years from \$1.58 per ton, f.o.b. plant, in 1970 to \$4.70 in 1991. However, the unit value in constant 1987 dollars fluctuated between \$3.37 and \$3.90 per ton for the same period, with a declining trend in the past 10 years. (See figure 2.)

Transportation

For 367 million tons or 33.3% of the total 1.1 billion tons of crushed stone produced in 1991, no means of transportation was reported by the producers. Of the remaining 736 million tons of crushed stone, 72.8% was reported as transported by truck from the processing plant or quarry to the first point of sale or use, 5.5% was transported by rail, and 6.3% by waterway. About 12.9% of the total production was reported as not transported and therefore used on-site. Information regarding means of transportation used by the producers to ship crushed stone in each geographic region is also provided. (See table 23.)

Foreign Trade

The widespread distribution of domestic crushed stone deposits and the high cost of transportation limits foreign trade mostly to local transactions across international boundaries. U.S. imports and exports are small, representing less than 0.5% of the domestic consumption. However, shipments of crushed stone by water from Canada and Mexico are increasing.

Exports.—Exports of crushed stone decreased 47.3% to 2.4 million tons compared with that of 1990, while value decreased 20.3% to \$33 million. About 93% of the exported crushed stone was limestone, Canada being the major destination with 99.5% of the total crushed stone. (See table 25.)

Imports.—Imports of crushed stone increased 14% to 5.7 million tons compared with that of 1990, while the value increased 9.3% to \$38.6 million. About 95.6% of the imported crushed stone was limestone, 46% of which came from Mexico, 28% from Canada, and 8% from the Bahamas. (See table 26.)

Imports of natural calcium carbonate fines decreased by 33% to 2,000 short tons. About 68% of processed calcium carbonate was imported from France. Shipments of crushed stone from Bahamas, Canada, and Mexico into the United States continued in 1991. The imported crushed stone, used mostly as construction aggregates or for cement manufacturing, was distributed in Alabama, Florida, Georgia, Louisiana, Michigan, New York, Ohio, Pennsylvania, Texas, and Washington. This trend is expected to continue, and the volume of imports, especially from Mexico, to increase.

World Review

Canada.—The 1990 production of stone in Canada was 111 million metric tons, a decrease of 6.7% from the revised final 1989 total of 119 million tons, valued at \$663 million. An additional 16 million tons of crushed stone was used in 1989 by the Canadian cement and lime industries. About 99% of the 1989 output was crushed or pulverized stone used for construction, chemical, metallurgical, and agricultural uses. The Province of Ontario continued to be the largest producer of stone, with 50.4 million tons valued at \$301 million, followed by Quebec with 40.6 million tons valued at \$244 million. The two Provinces accounted for 81.8% of the total stone production. Preliminary estimates for 1991 stone production indicate a significant decrease of 23% to 85.8 million tons valued at \$513 million. The Provinces of Ontario and Quebec continued to be the largest producers of stone with about 84% of the total output.

United Kingdom.—The 1990 production of crushed stone in Great

Britain (Northern Ireland not included) declined 4.1% compared with the record-high level of 1989, as reported by the British Aggregate Construction Materials Industries Association (BACMI). Of this total, 162 million tons was used for construction purposes. About 65% of the total output of crushed stone was limestone and dolomite. East Midlands and South West were the largest crushed stone-producing regions, followed by Wales and Scotland. Preliminary estimates made by BACMI indicate that a total of 168 million tons of crushed stone was produced in 1991, a 9% decrease compared with that of 1990.

Current Research

Recognizing the need for research into properties and adequate use of aggregates, crushed stone, and sand and gravel, as well as the need for reliable technical information in this area, the National Aggregates Association and the National Stone Association established in 1990 the Aggregates Foundation for Technology, Research, and Education (AFTRE.) The main purpose of the foundation is to establish and provide the funding for a new Aggregates Research Center. The crushed stone and sand and gravel industries representatives consider that the research plan of the Federal Strategic Highway Research Program, for example, does not adequately address the aggregate component of highway systems, while great emphasis is being placed on scientific research on the binders—*asphalt and cement and their associated admixtures and additives.* Both industries felt that they should take the lead in supporting scientific research that will address the key issues concerning aggregates and will contribute to the effective use of available resources. Therefore, the main goal of the foundation and the research center will be to support scientific research and education and develop and disseminate authoritative technical information related to construction aggregates. The comprehensive and objective information on construction aggregates developed by the research center will promote and

extend the effective and efficient use of aggregates in the construction industries. At the 1992 CON/AGG Show held in New Orleans, LA, between February 1 through February 6, 1992, the Board of Trustees of AFTRE announced the selection of the University of Texas at Austin and the Texas A&M University at College Station as the home of the new Aggregates Research Center.

Nineteen ninety-one was the fourth year of the 5-year Strategic Highway Research Program (SHRP), a program created in 1987 by the U.S. Congress. SHRP's mission is to produce usable research results targeted toward technical areas where there is potential for improvement of our highways and the materials used to build them, research that could also yield significant cost savings. SHRP's research activities account today for more than one-quarter of all highway research conducted in the United States by Federal agencies, States, and the private industry.

SHRP's four areas of research are asphalt, concrete and structures, highway operations, and long-term pavement performance. To improve the quality of pavements, better materials specifications and asphalt-concrete mixture design systems based on a scientific understanding of how asphalt properties influence performance are needed. SHRP made significant progress toward that goal in 1991.¹⁴

Based on results obtained through the use of state-of-the-art chemical and physical analysis techniques, researchers supported by SHRP have developed a chemical model of asphalt structure that, for the first time, explains how asphalt chemistry affects binder performance. Analysis of samples of asphalt using nuclear magnetic resonance (NMR) spectroscopy indicated that the molecular structures in asphalt are very small, contrary to the long-accepted "micellar" model that had pictured asphalt as relatively large lumps of materials in a sticky gel. At the same time, chemical analysis using ion-exchange chromatography indicated that the molecules that gave the asphalt most of its physical properties comprised only a

small portion of the total number of asphalt molecules. Based on these results, a model was produced that describes asphalt as a polar dispersed fluid and reconciles asphalt's chemical features with its physical behavior.

SHRP's concrete program is developing new engineering guidelines and materials tests that will help highway engineers produce more durable concrete consistently. Alkali-Silica Reactivity (ASR) of concrete is a damaging and difficult-to-detect problem in highway structures and a major area of concern for the highway and bridge inspectors. SHRP's Construction Technology Laboratories developed a new, quick chemical field test that uses uranyl acetate fluorescence to detect whether an ASR product has been formed in concrete. SHRP's Handbook for the Identification of Alkali-Silica Reactivity in Highway Structures provides guidance on proper diagnosis and assessment of ASR problems.¹⁵

SHRP's Long-Term Pavement Performance (LTPP) program addresses the issue of how best to use and protect the very large investment made every year in building and maintaining highway pavements. SHRP's LTPP program, the largest and most comprehensive pavement performance test in history, is collecting data on pavement conditions, climate, traffic, and load conditions over a 20-year period. The LTPP experiments involve testing of almost 1,000 in-service sections of the most common types of pavement design in use in the United States, as well as sections that have been specially constructed to isolate certain factors in pavement design.

The American Association of State Highway and Transportation Officials, the Federal Highway Administration, and the National Research Council have agreed on an approach to establish an oversight of continuing activities when some of SHRP's programs expire in 1992. The SHRP Monitoring and Research Transfer Committee will be created by the National Research Council that will include representatives from a broad spectrum of organizations, including

strong State highway agency representation.

Technology

The participants of the 1990 European Asphalt Study Tour sponsored by the Federal Highway Administration and the National Asphalt Pavement Associations concluded that there is "a lot to learn from Europe about asphalt pavements and about pavement philosophy in general. European pavements are better than ours. The Europeans invest more in research, development, and deployment of new pavement technology. They build their pavement foundations better. They use innovative surfaces, such as Stone Mastic Asphalt, and mix in additives to a greater extent and with better results."¹⁶ Stone Mastic Asphalt, also called Split Mastic Asphalt, is built using the stone-on-stone concept that develops internal friction and resistance to shear. The coarse aggregate is usually 100% crushed stone with a top size of 3/4 to 1/2 inches, and 70 to 80 percent by weight retained on the No. 10 sieve. The mix has a relatively high asphalt content of 6.5% to 7.5% and addition of cellulose or mineral wool fibers that improves the stability of the binder and prevents it from draining off the aggregate.¹⁷ A section of a highway near Lansing, MI, was selected by the Federal Highway Administration as a demonstration site to test the feasibility of using Stone Mastic Asphalt in the United States. Other demonstration projects are under way in Georgia and Wisconsin. According to the Michigan Department of Transportation, the Stone Mastic Asphalt mix provides high resistance to deformation (rutting), good wear resistance, improved low-temperature performance, improved aging and skid resistance properties, and increased service life. The cost of the Stone Mastic Asphalt is about 20% to 30% more than a conventional dense-graded surface course.¹⁸

Specialized computer services using high technology provide fast and accurate earthwork volume estimating to calculate production and stock inventories in aggregates operations. Computer

generated cross sections of the pit or quarry at very close intervals are generated, and very accurate calculations of volumes are performed. Valuable three-dimensional depth maps and two-dimensional cross sections of the operations can be also produced that can assist the plant operators or the designers of new pits and quarries.¹⁹

More aggregates-producing companies are automating their operations to remain competitive. Automated weighing and information processing systems in the crushed stone and sand and gravel industries are usually one of the first areas to be automated, especially in medium- to small-size operations. A properly selected and implemented computer-based data collection, storage, retrieval, and reporting system provides the operations with fewer mistakes, reduced expenses, and more timely available information. A review of present technology, software and hardware, and recommendations on how to select and implement the proper system in aggregates operations was published by Pit & Quarry.²⁰

Technologically, the aggregates industry is very complex and requires professionals with skills in a variety of areas, including geology and geophysical sciences, mining, materials, and geotechnical engineering and management. For a long time there has been a need for a comprehensive reference book covering the construction aggregates that can be used by producers, consulting and design engineers, and users. The Aggregate Handbook published by the National Stone Association in 1991 is just such a publication. The handbook covers all aspects of the sand and gravel and crushed stone industries from basic properties of aggregates, geology, exploration, extraction, and processing, to uses, standards and specifications, sampling and testing, marketing, and regulatory compliance. Numerous references are also provided for those interested for more in-depth information.²¹

OUTLOOK

The demand for crushed stone in 1992 is expected to be about 1.16 billion tons, a 5% increase compared with that of 1991. Gradual increases in demand for construction aggregates are anticipated after 1992 as well, based on increased volume of work on the infrastructure that is being financed by the Intermodal Surface Transportation and Infrastructure Act of 1991 and the recovery of the U.S. economy. It is estimated that the demand for crushed stone will reach 1.4 billion tons in 1995. The projected increases will be influenced by construction activity primarily in the public construction sector.

Crushed stone f.o.b. prices are not expected to increase significantly, even if the demand for construction aggregates will rise over the forecasts. However, the delivered prices of crushed stone are expected to increase, especially in and near metropolitan areas, mainly because more aggregates are transported from distant sources.

¹Boynton, R. S. *Chemistry and Technology of Lime and Limestone*. Wiley, 1980, p. 3.

²Barksdale, R. D. *The Aggregate Handbook*. National Stone Association, 1991, 800 pp.

³Oglesby, C. H. *Highway Engineering*. 1975, pp. 538-540.

⁴American Society for Testing and Materials. 1985 Annual Book of ASTM Standards: V. 04.03 Road and Paving Materials; Traveled Surface Characteristics. 1985, pp. 102-106.

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⁶Work cited in footnote 3.

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TABLE 1
SALIENT U.S. CRUSHED STONE STATISTICS

(Thousand short tons and thousand dollars)

		1987	1988	1989	1990	1991
Sold or used by producers:						
Quantity ¹	thousand short tons	1,200,100	*1,247,800	1,213,400	*1,222,000	1,102,900
Quantity	thousand metric tons ²	1,088,713	1,131,985	1,100,778	1,108,580	1,000,534
Value ¹	thousand dollars	\$5,248,600	*\$5,558,000	\$5,325,800	*\$5,591,300	\$5,186,800
Exports	value, thousand dollars	\$26,063	\$30,413	\$23,345	*\$41,400	\$33,003
Imports ³	do.	\$14,024	\$16,789	\$36,870	*\$35,310	\$38,649

*Estimated. Revised.

¹Does not include American Samoa, Guam, Puerto Rico, and the U.S. Virgin Islands.

²One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons into metric tons, multiply short tons by 0.907185.

³Excludes precipitated calcium carbonate.

TABLE 2
TIME-PRICE RELATIONSHIP FOR CRUSHED STONE

Year	Actual unit price	Unit prices in 1987 constant dollars	Unit prices in 1970 constant dollars
1970	\$1.58	\$3.77	\$1.58
1971	1.72	3.90	1.63
1972	1.72	3.71	1.56
1973	1.80	3.65	1.53
1974	2.00	3.73	1.56
1975	2.24	3.82	1.60
1976	2.35	3.77	1.58
1977	2.47	3.70	1.55
1978	2.64	3.67	1.54
1979	2.99	3.83	1.60
1980	3.32	3.88	1.63
1981	3.58	3.80	1.59
1982*	3.69	3.69	1.55
1983	3.87	3.72	1.56
1984*	3.93	3.62	1.52
1985	4.05	3.60	1.51
1986*	4.16	3.60	1.51
1987	4.37	3.66	1.53
1988*	4.37	3.52	1.48
1989	4.39	3.39	1.42
1990*	4.58	3.40	1.42
1991	4.70	3.37	1.41

*Estimated.

TABLE 3
CRUSHED STONE SOLD OR USED IN THE UNITED STATES, BY KIND

Kind	1989				1991			
	Number of quarries	Quantity (thousand short tons)	Value (thousands)	Unit value	Number of quarries	Quantity (thousand short tons)	Value (thousands)	Unit value
Limestone ¹	2,533	806,644	\$3,234,317	\$4.01	2,201	722,651	\$3,106,444	\$4.30
Dolomite	136	49,304	216,957	4.40	137	60,998	308,556	5.06
Marble	63	12,222	137,481	11.25	46	3,747	83,335	22.24
Calcareous marl	15	5,118	11,614	2.27	15	5,704	13,769	2.41
Shell	18	6,923	34,794	5.03	14	5,466	44,376	8.12
Granite	376	168,433	864,962	5.14	492	164,299	864,374	5.26
Traprock	446	99,161	524,271	5.29	561	83,327	485,223	5.82
Sandstone and quartzite	241	31,842	148,696	4.66	235	28,500	137,683	4.83
Slate	7	2,088	12,926	6.19	7	1,506	8,820	5.86
Volcanic cinder and scoria	118	3,630	20,206	5.57	117	2,041	11,546	5.66
Miscellaneous stone	110	28,065	119,538	4.26	188	24,690	122,695	4.97
Total ²	XX	1,213,400	5,325,800	4.39	XX	1,102,900	5,186,800	4.70

XX Not applicable.

¹Includes "Limestone-dolomite," reported with no distinction between the two.

²Data may not add to totals shown because of independent rounding.

TABLE 4
CRUSHED STONE¹ SOLD OR USED IN THE UNITED STATES, BY REGION

(Thousand short tons and thousand dollars)

Region	1990 ^a		1991	
	Quantity	Value	Quantity	Value
Northeast:				
New England	27,000	181,100	20,383	149,308
Middle Atlantic	157,500	845,700	124,130	688,173
Midwest:				
East North Central	218,200	845,200	221,639	870,824
West North Central	122,200	465,700	113,963	456,241
South:				
South Atlantic	308,500	1,575,600	254,064	1,332,320
East South Central	142,800	662,000	121,830	595,539
West South Central	130,600	481,500	122,883	483,164
West:				
Mountain	32,100	130,200	32,194	145,166
Pacific	82,900	404,400	91,790	466,087
Total ²	1,222,000	5,591,300	1,102,900	5,186,800

^aEstimated.

¹Includes volcanic cinder and scoria.

²Data may not add to totals shown because of independent rounding.

TABLE 5
CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1991,
BY QUARTER AND REGION

(Thousand short tons and thousand dollars)

Region	Quantity				Total	Value total	Percent coverage	Number of companies ¹
	1st quarter	2d quarter	3d quarter	4th quarter				
Northeast:								
New England	1,100	6,700	7,600	5,300	21,300	150,900	53	20
Middle Atlantic	15,900	37,500	42,500	31,900	128,000	704,000	64	40
Midwest:								
East North Central	23,500	55,800	64,800	51,300	195,300	771,800	71	50
West North Central	18,000	30,800	40,200	27,500	116,600	462,600	52	43
South:								
South Atlantic	46,100	69,300	71,700	60,600	246,900	1,261,500	80	46
East South Central	24,100	34,400	39,500	34,000	132,800	602,800	68	20
West South Central	24,900	31,300	35,500	26,400	114,700	442,300	61	33
West:								
Mountain	4,300	6,800	11,800	7,100	28,900	121,900	48	26
Pacific ²	12,900	15,700	18,500	14,800	63,600	293,400	44	26
Total³	170,500	288,300	332,200	258,900	*1,061,700	*4,897,100	XX	XX

XX Not applicable.

¹Number of companies reporting for the quarterly survey.

²Does not include Alaska and Hawaii.

³Data may not add to totals shown because of independent rounding and differences between projected totals by states and by regions.

*Includes Alaska, Hawaii, and "Other" totals; these totals represent preliminary estimates and, therefore, do not equal the final totals resulting from the annual survey.

TABLE 6
CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE¹

(Thousand short tons and thousand dollars)

State	1990*			1991		
	Quantity	Value	Unit value	Quantity	Value	Unit value
Alabama	36,100	202,400	5.61	² 27,145	² 161,843	5.96
Alaska	2,700	19,800	7.33	⁴ 1,085	⁴ 6,688	4.32
Arizona	5,300	13,500	2.55	7,060	32,842	4.65
Arkansas	17,800	76,900	4.32	² 22,140	² 101,427	4.58
California	42,500	200,600	4.72	45,816	216,156	4.72
Colorado	7,600	36,100	4.75	8,401	41,022	4.88
Connecticut	10,200	70,600	6.92	² 65,873	² 52,701	8.97
Florida	74,400	317,400	4.27	⁷ 59,132	⁷ 260,901	4.41
Georgia	53,000	317,300	5.99	⁶ ⁷ 41,339	⁶ ⁷ 222,900	5.39
Hawaii	7,000	55,400	7.91	⁶ 10,486	⁶ 90,563	8.64
Idaho	4,300	12,900	3.00	3,230	15,057	4.66
Illinois	62,700	283,100	4.52	68,586	⁴ 102,953,62	4.31
Indiana	36,700	147,400	4.02	37,924	152,489	4.02
Iowa	29,000	118,600	4.09	² ¹⁰ 31,057	² ¹⁰ 147,815	4.76
Kansas	20,800	79,200	3.81	¹¹ 16,802	¹¹ 67,249	4.00
Kentucky	50,100	182,900	3.65	46,266	191,893	4.15
Louisiana	2,100	16,800	8.00	⁶ ¹² W	⁶ ¹² W	9.34
Maine	1,700	8,700	5.12	1,706	9,899	5.80
Maryland	30,500	163,900	5.37	25,545	188,001	7.36
Massachusetts	9,200	54,500	5.92	7,131	51,362	7.20
Michigan	43,100	129,000	2.99	40,989	129,490	3.16
Minnesota	9,100	31,900	3.51	8,378	30,624	3.66
Mississippi	1,400	5,500	3.93	1,632	6,603	4.05
Missouri	53,100	190,900	3.60	47,938	167,233	3.49
Montana	4,000	15,300	3.83	2,107	5,725	2.72
Nebraska	4,000	21,200	5.30	4,861	23,328	4.80
Nevada	1,600	5,000	3.13	1,199	6,527	5.45
New Hampshire	600	2,500	4.17	1,452	9,148	6.30
New Jersey	21,200	131,700	6.21	⁴ 16,680	⁴ 119,287	7.15
New Mexico	2,400	12,800	5.33	2,801	13,089	4.67
New York	39,900	207,600	5.20	34,871	195,639	5.61
North Carolina	52,900	276,200	5.22	⁹ ¹¹ ¹³ 46,514	⁹ ¹¹ ¹³ 243,920	5.26
North Dakota	1,000	4,600	4.60	11	⁹ W	W
Ohio	48,400	190,900	3.94	¹⁰ 47,310	¹⁰ 184,177	3.89
Oklahoma	25,300	89,500	3.54	³ 25,678	³ 95,509	3.72
Oregon	18,000	86,600	4.81	¹³ 20,608	¹³ 89,322	4.33
Pennsylvania	95,800	502,700	5.25	¹⁰ ¹¹ 70,334	¹⁰ ¹¹ 362,306	5.15
Rhode Island	1,600	8,800	5.50	1,187	7,262	6.12
South Carolina	26,200	135,400	5.17	² 18,216	² 84,260	4.63
South Dakota	4,800	16,800	3.50	4,824	19,657	4.08
Tennessee	54,600	268,600	4.92	44,088	223,561	5.07
Texas	81,800	285,700	3.49	65,813	226,836	3.45
Utah	4,600	20,200	4.39	4,450	18,259	4.10
Vermont	3,700	35,000	9.46	2,685	12,666	4.72
Virginia	59,400	320,000	5.39	48,861	260,966	5.34
Washington	12,700	41,900	3.30	13,126	59,588	4.54
West Virginia	12,000	45,200	3.77	10,255	50,505	4.92

See footnotes at end of table.

TABLE 6—Continued
CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE¹

(Thousand short tons and thousand dollars)

State	1990 ^a			1991		
	Quantity	Value	Unit value	Quantity	Value	Unit value
Wisconsin	26,600	91,000	3.42	⁵ 23,676	⁵ 80,475	3.40
Wyoming	2,200	14,000	6.36	2,946	12,645	4.29
Other	6,300	26,500	4.21	22,664	144,044	6.36
Total ¹⁴	1,222,000	5,591,300	4.58	1,102,900	5,186,800	4.70

^aEstimated. W Withheld to avoid disclosing company proprietary data; included with "Other."

¹To avoid disclosing company proprietary data, certain State totals do not include all kinds of stone produced within the State; the portion not shown has been included with "Other."

²Excludes dolomite.

³Excludes granite.

⁴Excludes sandstone.

⁵Excludes traprock.

⁶Excludes other.

⁷Excludes calcareous marl.

⁸Excludes marble.

⁹Excludes volcanic cinders.

¹⁰Excludes limestone-dolomite.

¹¹Excludes quartzite.

¹²Excludes shell.

¹³Excludes slate.

¹⁴Data may not add to totals shown because of independent rounding.

TABLE 7
**CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES
 IN 1991, BY QUARTER AND STATE**

(Thousand short tons and thousand dollars)

State	Quantity					Value total	Percent coverage	Number of companies ¹
	1st quarter	2d quarter	3d quarter	4th quarter	Total			
Alabama ²	7,500	8,000	8,900	8,200	32,600	178,500	81	13
Alaska ³	—	—	—	—	2,000	14,700	—	—
Arizona	1,300	1,200	1,300	1,300	5,100	12,800	27	3
Arkansas ²	3,500	5,200	6,000	4,300	19,000	81,600	58	8
California	6,600	9,000	10,300	8,600	34,500	162,900	53	13
Colorado ²	1,100	2,000	2,800	1,700	7,600	36,200	64	7
Connecticut ²	400	2,400	2,500	2,200	7,500	50,300	43	5
Delaware	—	—	—	—	—	—	—	—
Florida	12,500	14,500	14,700	14,700	56,400	247,700	61	12
Georgia	7,800	11,600	13,900	11,300	44,600	262,400	89	8
Hawaii ³	—	—	—	—	6,000	47,600	—	—
Idaho ³	—	—	—	—	3,000	10,000	—	—
Illinois ²	6,700	15,800	20,200	13,800	56,500	262,300	68	14
Indiana ²	5,300	10,300	10,000	7,800	33,400	135,500	81	15
Iowa	3,600	6,500	11,300	6,700	28,100	134,200	51	8
Kansas ²	3,400	5,500	6,200	4,500	19,600	75,000	60	12
Kentucky ²	8,800	13,000	16,500	14,000	52,300	189,000	61	9
Louisiana ³	—	—	—	—	2,500	20,000	—	—
Maine	100	700	700	400	1,900	9,700	35	3
Maryland	3,500	6,600	6,800	4,800	21,700	123,500	97	10
Massachusetts	400	2,300	2,700	1,900	7,300	43,200	55	6
Michigan	2,900	11,700	12,400	11,200	38,200	113,900	81	10
Minnesota	300	1,900	4,000	1,800	8,000	28,800	68	6
Mississippi ³	—	—	—	—	900	4,000	—	—
Missouri	10,200	14,200	14,600	12,900	51,900	184,300	41	16
Montana	200	800	1,100	700	2,800	11,500	38	4
Nebraska	700	1,200	1,400	800	4,100	22,800	116	6
Nevada	300	400	400	300	1,400	4,700	45	3
New Hampshire ³	—	—	—	—	300	1,300	—	—
New Jersey	1,900	4,300	5,200	4,400	15,800	112,400	89	8
New Mexico	300	700	900	600	2,500	13,300	42	4
New York	3,600	10,900	12,500	8,200	35,200	186,200	71	12
North Carolina	8,000	13,000	12,900	11,400	45,300	229,700	97	11
North Dakota ³	—	—	—	—	—	—	—	—
Ohio	6,400	11,300	13,500	12,200	43,400	174,200	73	14
Oklahoma ²	3,500	5,800	7,300	5,600	22,200	83,100	82	11
Oregon ²	3,400	3,500	4,600	3,900	15,400	75,700	37	10
Pennsylvania ²	10,700	22,400	24,700	19,200	77,000	405,400	56	24
Rhode Island ^{2 3}	—	—	—	—	1,100	6,600	—	—
South Carolina ²	4,800	6,100	6,300	6,000	23,200	112,700	79	8
South Dakota	500	1,500	1,700	1,200	4,900	17,500	65	5
Tennessee	7,400	13,500	14,300	11,800	47,000	231,300	66	9
Texas	16,600	18,400	19,500	16,500	71,000	257,600	54	17
Utah	600	500	1,600	1,100	3,800	14,900	39	3

See footnotes at end of table.

TABLE 7—Continued
**CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES
 IN 1991, BY QUARTER AND STATE**

(Thousand short tons and thousand dollars)

State	Quantity					Value total	Percent coverage	Number of companies ¹
	1st quarter	2d quarter	3d quarter	4th quarter	Total			
Vermont	200	1,000	1,300	700	3,200	39,800	52	3
Virginia	8,400	14,200	13,100	10,300	46,000	247,400	76	16
Washington	3,900	3,600	4,200	2,000	13,700	54,800	23	4
West Virginia ²	1,600	2,900	3,100	2,100	9,700	38,100	49	5
Wisconsin	1,900	6,500	9,300	6,100	23,800	85,900	46	9
Wyoming	300	400	1,600	400	2,700	18,500	99	5
Other ³	—	—	—	—	5,600	23,600	—	—
Total⁴	XX	XX	XX	XX	1,061,700	4,897,100	XX	XX

XX Not applicable.

¹Number of companies reporting for the quarterly survey.

²Because of a low number of reporting companies, no production estimates by quarters were generated.

³To avoid disclosing company proprietary data, certain State totals do not include all kinds of stone produced within the State; the portion not shown has been included with "Other."

⁴These totals represent preliminary estimates, and therefore, do not equal the final totals resulted from the annual survey.

TABLE 8
CRUSHED STONE SOLD OR USED IN THE UNITED STATES IN 1991,
BY REGION AND SIZE OF OPERATION

Size range (short tons)	Northeast				Midwest			
	Number of opera- tions	Percent of total	Quantity (thou- sand short tons)	Percent of total	Number of opera- tions	Percent of total	Quantity (thou- sand short tons)	Percent of total
Less than 25,000	43	10.9	312	0.2	275	22.9	2,832	0.8
25,000 to 49,999	24	6.1	898	.6	147	12.3	5,498	1.6
50,000 to 99,999	41	10.4	3,082	2.1	184	15.3	13,270	4.0
100,000 to 199,999	61	15.4	8,793	6.1	198	16.5	28,928	8.6
200,000 to 299,999	62	15.7	15,104	10.5	118	9.8	28,704	8.6
300,000 to 399,999	36	9.1	12,832	8.9	62	5.2	21,658	6.5
400,000 to 499,999	33	8.4	14,952	10.3	40	3.3	17,651	5.3
500,000 to 599,999	27	6.8	14,920	10.3	33	2.8	18,446	5.5
600,000 to 699,999	15	3.8	9,759	6.8	24	2.0	15,223	4.5
700,000 to 799,999	13	3.3	9,775	6.8	27	2.3	20,381	6.1
800,000 to 899,999	8	2.0	6,901	4.8	21	1.8	17,860	5.3
900,000 to 999,999	4	1.0	3,772	2.6	12	1.0	11,423	3.4
1,000,000 to 1,499,999	21	5.3	24,449	16.9	30	2.5	36,748	10.9
1,500,000 to 1,999,999	2	.5	W	2.4	13	1.1	W	6.8
2,000,000 to 2,499,999	2	.5	W	3.1	1	.1	W	.7
2,500,000 to 4,999,999	3	.8	11,014	7.6	8	.7	23,895	7.1
5,000,000 and over	—	—	—	—	7	.6	48,114	14.3
Total	395	100.0	144,500	100.0	1,200	100.0	355,600	100.0

Size range (short tons)	South				West				U.S. total ¹			
	Number of opera- tions	Percent of total	Quantity (thou- sand short tons)	Percent of total	Number of opera- tions	Percent of total	Quantity (thou- sand short tons)	Percent of total	Number of opera- tions	Percent of total	Quantity (thou- sand short tons)	Percent of total
Less than 25,000	86	8.5	839	0.2	226	33.0	2,210	1.8	630	19.2	6,192	0.6
25,000 to 49,999	60	6.0	2,232	.4	108	15.8	3,968	3.2	339	10.3	12,596	1.1
50,000 to 99,999	102	10.1	7,552	1.5	101	14.8	7,137	5.8	428	13.0	31,042	2.8
100,000 to 199,999	141	14.0	20,545	4.1	95	13.9	13,905	11.2	495	15.1	72,171	6.5
200,000 to 299,999	102	10.1	25,317	5.1	50	7.3	12,203	9.8	332	10.1	81,328	7.4
300,000 to 399,999	95	9.4	33,158	6.6	26	3.8	9,102	7.3	219	6.7	76,751	7.0
400,000 to 499,999	73	7.2	33,041	6.6	17	2.5	7,747	6.2	163	5.0	73,392	6.7
500,000 to 599,999	72	7.1	39,556	7.9	13	1.9	7,232	5.8	145	4.4	80,154	7.3
600,000 to 699,999	44	4.4	28,408	5.7	5	.7	3,296	2.7	88	2.7	56,686	5.1
700,000 to 799,999	42	4.2	31,390	6.3	7	1.0	5,269	4.2	89	2.7	66,815	6.1
800,000 to 899,999	41	4.1	35,120	7.0	5	.7	4,248	3.4	75	2.3	64,130	5.8
900,000 to 999,999	29	2.9	27,905	5.6	5	.7	4,750	3.8	50	1.5	47,851	4.3
1,000,000 to 1,499,999	67	6.6	80,183	16.1	13	1.9	15,058	12.1	131	4.0	156,437	14.2
1,500,000 to 1,999,999	29	2.9	48,869	9.8	6	.9	10,424	8.4	50	1.5	85,402	7.7
2,000,000 to 2,499,999	8	.8	17,932	3.6	4	.6	8,927	7.2	15	.5	33,670	3.1
2,500,000 to 4,999,999	14	1.4	47,425	9.5	3	.4	8,507	6.9	28	.9	90,841	8.2
5,000,000 and over	3	.3	19,305	3.9	—	—	—	—	10	.3	67,418	6.1
Total¹	1,008	100.0	498,800	100.0	684	100.0	124,000	100.0	3,287	100.0	1,102,900	100.0

W Withheld to avoid disclosing company proprietary data; included with "Total."

¹Data may not add to totals shown because of independent rounding.

²Data do not add to total shown because of multiple kinds of stone reported by same operation.

TABLE 9
CRUSHED LIMESTONE AND DOLOMITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1991,
BY STATE

(Thousand short tons and thousand dollars)

State	Limestone		Dolomite	
	Quantity	Value	Quantity	Value
Alabama	25,512	100,647	W	W
Alaska	56	225	—	—
Arizona	4,166	18,635	—	—
Arkansas	6,492	26,422	W	W
California	20,062	84,363	131	1,117
Colorado	3,175	13,863	—	—
Connecticut	874	7,672	W	W
Florida	57,076	250,740	906	5,059
Georgia	4,848	30,939	180	1,040
Hawaii	2,804	24,471	—	—
Idaho	1,027	5,274	—	—
Illinois	¹ 59,243	¹ 268,328	8,923	39,363
Indiana	35,549	142,747	2,375	9,742
Iowa	¹ 30,998	¹ 147,659	W	W
Kansas	16,494	66,401	—	—
Kentucky	46,266	191,893	—	—
Maine	837	4,348	—	—
Maryland	16,236	130,700	—	—
Michigan	36,203	113,675	4,503	14,743
Minnesota	6,806	24,005	W	W
Mississippi	1,632	6,603	—	—
Missouri	¹ 44,698	¹ 155,631	1,652	6,221
Montana	1,045	2,875	—	—
Nebraska	4,861	23,328	—	—
New Jersey	460	4,416	—	—
New Mexico	1,287	4,241	—	—
New York	¹ 24,565	¹ 116,359	7,852	58,695
North Carolina	3,827	20,941	176	1,075
Ohio	¹ 44,165	¹ 174,262	4,480	16,297
Oklahoma	23,835	87,682	—	—
Oregon	1,382	6,418	—	—
Pennsylvania	¹ 41,122	¹ 214,913	12,701	60,814
South Carolina	2,487	10,935	W	W
South Dakota	2,619	7,667	—	—
Tennessee	38,524	196,188	W	W
Texas	¹ 60,277	¹ 195,269	W	W
Utah	2,990	12,590	W	W
Vermont	1,342	6,177	215	1,369
Virginia	15,258	71,874	2,914	25,239
Washington	¹ 1,521	¹ 10,766	9	W
West Virginia	7,327	37,248	W	² W
Wisconsin	20,476	71,179	190	813
Wyoming	514	1,402	W	W
Other	² 1,710	² 14,474	³ 13,792	³ 66,966
Total⁴	722,700	3,106,400	61,000	308,600

W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Includes "limestone-dolomite," reported with no distinction between the two.

²Includes data for Massachusetts, Nevada, New Hampshire, and Rhode Island.

³Includes data for Massachusetts and Nevada.

⁴Data may not add to totals shown because of independent rounding.

TABLE 10
CRUSHED MARBLE SOLD OR USED BY PRODUCERS
IN THE UNITED STATES IN 1991, BY STATE

(Thousand short tons and thousand dollars)

State	Quantity	Value
Alabama	1,553	60,973
California	583	2,931
New York	85	3,354
Other ¹	1,484	16,078
Total²	3,700	83,300

¹Includes data for Arizona, Colorado, Georgia, Michigan, Nevada, New Mexico, Pennsylvania, Texas, Vermont, Virginia, and Wyoming.

²Data may not add to totals shown because of independent rounding.

TABLE 11
CRUSHED CALCAREOUS MARL SOLD OR USED BY PRODUCERS
IN THE UNITED STATES IN 1991, BY STATE

(Thousand short tons and thousand dollars)

State	Quantity	Value
South Carolina	3,296	6,812
Other ¹	2,408	6,957
Total²	5,700	13,800

¹Includes data for Florida, Georgia, Michigan, North Carolina, and Texas.

²Data may not add to totals shown because of independent rounding.

TABLE 12
**CRUSHED GRANITE, TRAPROCK, AND SANDSTONE AND QUARTZITE SOLD OR USED BY PRODUCERS
 IN THE UNITED STATES IN 1991, BY STATE**

(Thousand short tons and thousand dollars)

State	Granite		Traprock		Sandstone and quartzite	
	Quantity	Value	Quantity	Value	Quantity	Value
Alabama	W	W	—	—	38	222
Alaska	W	1,178	305	1,576	W	W
Arizona	2,144	10,192	73	W	W	W
Arkansas	W	W	W	W	4,119	17,080
California	8,504	38,418	9,466	63,131	W	W
Colorado	4,353	22,766	W	W	369	1,558
Connecticut	224	1,646	4,775	43,383	—	—
Georgia	36,027	189,388	—	—	W	W
Hawaii	283	2,981	7,269	62,534	—	—
Idaho	322	W	1,189	4,324	338	W
Illinois	—	—	—	—	420	W
Kansas	—	—	—	—	W	849
Maine	W	W	W	W	W	W
Maryland	5,633	33,155	W	W	W	W
Massachusetts	2,197	17,464	3,575	17,663	—	—
Michigan	—	—	14	36	W	346
Minnesota	W	W	W	W	W	W
Missouri	W	W	100	373	177	W
Montana	531	864	W	W	195	667
Nevada	33	53	W	W	—	—
New Hampshire	1,056	5,796	W	W	—	—
New Jersey	7,454	54,955	8,766	59,916	W	W
New Mexico	902	5,286	124	267	W	W
New York	1,006	5,697	W	W	W	W
North Carolina	38,095	198,834	2,539	14,374	W	W
Ohio	—	—	—	—	W	1,089
Oklahoma	W	W	1,025	4,305	813	3,518
Oregon	380	W	16,594	71,632	344	1,589
Pennsylvania	1,968	W	4,108	22,609	5,921	30,548
South Carolina	12,298	65,959	—	—	—	—
South Dakota	W	W	—	—	2,195	11,949
Tennessee	W	1,927	—	—	W	W
Texas	W	W	W	4,641	1,542	9,530
Utah	—	—	—	—	W	W
Vermont	265	1,792	(¹)	1	W	W
Virginia	19,185	101,034	9,170	51,105	1,942	9,910
Washington	798	3,125	9,733	40,999	126	575
West Virginia	W	W	—	—	977	5,163
Wisconsin	1,466	3,239	W	W	W	W
Wyoming	W	W	W	W	W	W
Other	19,175	98,624	4,501	22,352	8,928	43,089
Total ²	164,300	864,400	83,300	485,200	28,400	137,700

¹ Withheld to avoid disclosing company proprietary data; included with "Other."
² Less than 1/2 unit.

Data may not add to totals shown because of independent rounding.

TABLE 13
**CRUSHED VOLCANIC CINDER AND SCORIA AND MISCELLANEOUS CRUSHED STONE SOLD OR USED BY
 PRODUCERS IN THE UNITED STATES IN 1991, BY STATE**

(Thousand short tons and thousand dollars)

State	Volcanic cinder and scoria		Miscellaneous stone	
	Quantity	Value	Quantity	Value
Alaska	70	200	163	1,477
Arizona	26	52	W	W
Arkansas	—	—	1,650	8,629
California	491	2,517	3,010	12,777
Hawaii	W	576	W	W
Iowa	—	—	111	304
Missouri	—	—	18	43
Nevada	21	535	W	W
New Mexico	265	2,142	W	W
New York	—	—	17	43
North Carolina	W	W	1,583	8,365
North Dakota	11	W	—	—
Oregon	298	1,316	1,610	6,563
Pennsylvania	—	—	6,234	29,680
Texas	—	—	1,256	3,402
Vermont	—	—	W	1,347
Washington	151	W	787	2,848
Other	¹ 708	¹ 4,210	² 8,252	² 47,219
Total³	2,000	11,500	24,700	122,700

W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Includes data for Colorado, Idaho, Montana, Utah, and Wyoming.

²Includes data for Colorado, Connecticut, Georgia, Idaho, Louisiana, Maine, Maryland, Massachusetts, Michigan, Montana, New Hampshire, New Jersey, South Dakota, Tennessee, Virginia, Wisconsin, and Wyoming.

³Data may not add to totals shown because of independent rounding.

TABLE 14
KIND OF CRUSHED STONE PRODUCED IN THE UNITED STATES IN 1991, BY STATE

State	Lime- stone	Dolo- mite	Marble	Marl	Shell	Granite	Trap- rock	Sand- stone	Quartzite	Slate	Volcanic cinder and scoria	Miscella- neous
Alabama	X	X	X			X		X				
Alaska	X					X	X	X		X	X	X
Arizona	X		X			X	X	X	X		X	X
Arkansas	X	X				X	X	X				X
California	X	X	X		X	X	X	X	X	X	X	X
Colorado	X		X			X	X	X	X		X	X
Connecticut	X	X				X	X					X
Florida	X	X		X	X							
Georgia	X	X	X	X		X			X			X
Hawaii	X					X	X				X	X
Idaho	X				X	X	X		X		X	X
Illinois	X	X						X				
Indiana	X	X										
Iowa	X	X										X
Kansas	X							X	X			
Kentucky	X											
Louisiana					X							X
Maine	X					X	X		X			X
Maryland	X					X	X	X				X
Massachusetts	X	X				X	X					X
Michigan	X	X	X	X			X	X				X
Minnesota	X	X				X	X		X			
Mississippi	X											
Missouri	X	X				X	X	X				X
Montana	X					X	X	X	X		X	X
Nebraska	X											
Nevada	X	X				X	X				X	X
New Hampshire	X					X	X					X
New Jersey	X					X	X	X				X
New Mexico	X		X			X	X	X	X		X	X
New York	X	X	X			X	X	X				X
North Carolina	X	X		X		X	X		X	X	X	X
North Dakota											X	
Ohio	X	X						X				
Oklahoma	X				X	X	X	X				
Oregon	X					X	X	X		X	X	X
Pennsylvania	X	X				X	X	X	X			X
Rhode Island	X					X	X					
South Carolina	X	X		X	X	X						
South Dakota	X					X		X	X			X
Tennessee	X	X				X		X				X
Texas	X	X	X	X		X	X	X	X			X
Utah	X	X						X			X	
Vermont	X	X	X			X	X		X			X
Virginia	X	X				X	X	X	X	X		X
Washington	X	X				X	X	X			X	X
West Virginia	X	X				X		X				
Wisconsin	X	X				X	X	X				X

TABLE 14—Continued
KIND OF CRUSHED STONE PRODUCED IN THE UNITED STATES IN 1991, BY STATE

State	Lime- stone	Dolo- mite	Marble	Marl	Shell	Granite	Trap- rock	Sand- stone	Quartzite	Slate	Volcanic cinder and scoria	Miscella- neous
Wyoming	X	X	X			X	X		X		X	X
American Samoa							X					
Guam	X											
Puerto Rico	X		X			X		X				X
Virgin Islands	X						X					

TABLE 15
CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1991, BY USE

(Thousand short tons and thousand dollars)

Use	Quantity	Value	Unit value
Coarse aggregate (+1 inch):			
Macadam	4,426	19,653	4.44
Riprap and jetty stone	22,612	111,081	4.91
Filter stone	7,911	35,048	4.43
Other coarse aggregate	579	2,641	4.56
Coarse aggregate, graded:			
Concrete aggregate, coarse	100,793	491,761	4.88
Bituminous aggregate, coarse	78,227	423,372	5.41
Bituminous surface-treatment aggregate	28,980	143,572	4.95
Railroad ballast	18,074	84,862	4.70
Other graded coarse aggregate	696	1,202	1.73
Fine aggregate (-3/8 inch):			
Stone sand, concrete	20,672	112,498	5.44
Stone sand, bituminous mix or seal	24,330	112,772	4.64
Screening, undesignated	26,989	115,084	4.26
Other fine aggregate	427	2,863	6.70
Coarse and fine aggregates:			
Graded road base or subbase	179,536	723,335	4.03
Unpaved road surfacing	30,546	128,099	4.19
Terrazzo and exposed aggregate	2,208	18,910	8.56
Crusher run or fill or waste	39,441	162,695	4.13
Other coarse and fine aggregates	1,348	8,223	6.10
Other construction materials ¹	23,767	119,020	5.01
Roofing granules	4,545	27,254	6.00
Agricultural:			
Agricultural limestone	18,133	94,412	5.21
Poultry grit and mineral food	3,187	31,780	9.97
Other agricultural uses	982	5,782	5.89
Chemical and metallurgical:			
Cement manufacture	85,386	266,014	3.12
Lime manufacture	18,647	103,139	5.53
Dead-burned dolomite manufacture	1,511	5,733	3.70
Flux stone	5,143	24,501	4.76
Chemical stone	337	1,891	5.61

See footnotes at end of table.

TABLE 15—Continued
CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1991, BY USE

(Thousand short tons and thousand dollars)

Use	Quantity	Value	Unit value
Chemical and metallurgical—Continued:			
Glass manufacture	908	9,829	10.82
Sulfur oxide removal	2,249	12,551	5.58
Special:			
Mine dusting or acid water treatment	964	13,094	13.58
Asphalt fillers or extenders	2,418	17,606	7.28
Whiting or whiting substitute	866	28,619	33.05
Other fillers or extenders	4,577	85,598	18.70
Other miscellaneous uses:			
Chemicals	601	3,281	5.46
Abrasives	16	81	5.06
Magnesia (dolomite)	18	30	1.67
Other specified uses not listed ²	346	4,224	12.21
Unspecified:³			
Actual	259,223	1,255,712	4.84
Estimated	81,253	378,997	4.66
Total⁴	1,102,900	5,186,800	4.70

¹Includes dam construction, drain fields, lightweight aggregate (slate), building products, pipe bedding, and waste material.

²Includes refractory stone (including ganister) and paper manufacture.

³Includes production reported without a breakdown by use and estimates for nonrespondents.

⁴Data may not add to totals shown because of independent rounding.

TABLE 16
CRUSHED LIMESTONE¹ AND DOLOMITE SOLD OR USED BY PRODUCERS
 (Thousand short tons)

State	Concrete aggregate		Bituminous aggregate		Roadstone and coverings		Riprap and rail-road ballast		Other construction uses	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Alabama	3,412	13,520	4,445	20,836	3,278	12,900	1,096	4,640	3,085	12,229
Alaska	—	—	—	—	56	225	—	—	—	—
Arizona	W	W	W	W	W	W	W	W	W	W
Arkansas	158	775	258	2,024	811	3,431	119	517	190	774
California	108	714	988	2,744	1,417	4,553	W	W	138	316
Colorado	W	W	W	W	55	192	69	301	54	127
Connecticut	(²)	1	—	—	2	12	(²)	1	W	153
Florida	18,134	95,195	6,546	32,452	13,591	43,153	299	1,117	6,306	19,767
Georgia	901	5,022	357	2,172	510	2,559	22	154	674	3,433
Hawaii	W	W	—	—	982	8,293	—	—	478	3,982
Idaho	—	—	15	56	—	—	—	—	16	229
Illinois	9,515	41,241	11,638	52,765	17,782	70,443	891	4,172	2,176	9,582
Indiana	4,394	14,311	3,939	14,375	3,633	14,716	1,839	7,828	3,334	16,096
Iowa	1,602	8,240	3,762	19,277	6,508	28,190	238	1,235	1,292	4,530
Kansas	1,305	6,677	1,772	8,138	2,983	9,850	77	480	963	3,917
Kentucky	6,421	24,362	6,484	26,253	9,367	36,024	3,414	13,323	4,568	15,653
Maine	—	—	—	—	—	—	—	—	—	—
Maryland	325	1,515	562	2,662	641	2,507	67	347	1,028	4,118
Massachusetts	—	—	—	—	—	—	—	—	W	W
Michigan	1,983	7,922	1,588	6,055	4,340	15,595	339	1,793	350	1,560
Minnesota	300	1,112	472	1,714	2,143	7,657	88	349	817	2,973
Mississippi	W	W	W	W	W	W	W	W	W	W
Missouri	3,417	12,386	3,472	13,272	10,568	39,260	4,002	11,359	2,002	8,639
Montana	—	—	—	—	—	—	—	—	—	—
Nebraska	W	W	223	1,311	534	3,047	55	358	477	2,548
Nevada	—	—	—	—	—	—	—	—	—	—
New Hampshire	—	—	—	—	—	—	—	—	—	—
New Jersey	30	360	28	378	60	315	—	—	175	1,826
New Mexico	251	716	33	47	231	579	(²)	—	76	104
New York	2,068	11,421	4,307	24,597	3,046	15,958	284	2,032	2,454	10,698
North Carolina	W	W	68	247	184	793	W	W	146	467
Ohio	3,855	15,546	3,435	14,167	17,527	64,427	2,241	8,159	2,733	10,633
Oklahoma	2,320	9,617	819	3,580	1,537	4,708	163	790	1,643	4,376
Oregon	—	—	—	—	—	—	—	—	W	W
Pennsylvania	2,615	12,642	7,504	39,751	4,911	21,827	1,026	5,888	3,882	16,676
Rhode Island	—	—	—	—	—	—	—	—	W	W
South Carolina	W	1,040	W	520	W	2,656	—	—	W	W
South Dakota	W	W	W	W	W	W	W	W	W	W
Tennessee	3,226	15,394	6,672	31,293	9,346	41,946	1,401	6,128	6,480	27,728
Texas	8,409	31,355	5,398	23,249	13,816	34,195	650	3,064	3,406	6,752
Utah	—	—	—	—	W	W	31	98	69	166
Vermont	—	—	—	—	—	—	—	—	—	—
Virginia	1,850	9,437	1,181	5,702	1,537	6,818	353	1,768	2,674	12,679
Washington	—	—	13	W	—	—	W	W	2,026	10,163
West Virginia	892	4,795	842	3,668	1,078	6,294	207	1,272	1,020	3,254
Wisconsin	1,509	5,620	1,610	5,731	7,038	25,107	124	558	1	2
Wyoming	—	—	—	—	—	—	3	3	54,733	216,150
Total (excludes withheld) ²	79,000	350,222	78,431	359,036	139,512	528,230	19,098	77,734	54,733	216,150
Total withheld	2,817	12,808	780	2,879	858	858	373	1,752	814	6,609
Grand total	81,187	363,030	79,211	361,915	140,370	529,088	19,471	79,486	55,547	222,759
Guam	W	10,539	W	1,687	W	2,863	W	88	W	2,861
Puerto Rico	1,927	11,187	W	W	W	W	—	—	41	484
Virgin Island	W	W	W	W	—	—	W	W	—	—

W Withheld to avoid disclosing company proprietary data; included with "Total withheld" and "Other uses." XX Not applicable.

¹Includes a minor amount of limestone-dolomite reported without a distinction between the two.

²Data may not add to totals shown because of independent rounding.

³Less than 1/2 unit.

IN THE UNITED STATES IN 1989, BY STATE AND USE
and thousand dollars)

Cement manufacture		Agricultural uses		Lime manufacture		Other uses		Total ²	
Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
2,120	5,610	1,016	4,107	3,542	13,599	3,518	13,206	25,512	100,647
—	—	—	—	—	—	—	—	56	225
2,017	9,825	—	—	W	W	2,149	8,810	4,166	18,635
W	W	W	W	—	—	4,955	18,900	6,492	26,422
12,971	45,064	W	W	110	1,085	4,330	30,602	20,062	84,363
W	W	69	720	W	W	2,928	12,524	3,175	13,864
—	—	W	W	—	—	873	7,506	874	7,672
3,345	15,107	1,222	8,619	—	—	7,633	35,330	57,076	250,740
—	—	—	—	—	—	2,384	17,600	4,848	30,939
339	2,738	W	200	—	—	1,005	9,258	2,804	24,471
W	W	41	186	—	—	954	4,802	1,027	5,274
3,023	11,642	3,452	12,977	W	W	10,766	65,504	59,243	268,326
3,529	8,711	1,544	8,683	—	—	13,338	58,028	35,549	142,747
2,225	5,903	1,900	13,403	W	W	13,471	66,881	30,998	147,659
1,907	5,265	186	642	—	—	7,300	31,433	16,494	66,401
W	W	1,243	5,487	W	W	14,769	70,791	46,266	191,893
W	W	—	—	—	—	837	4,348	837	4,348
2,451	4,991	—	—	—	—	11,161	114,560	16,236	130,700
—	—	W	W	W	W	W	W	W	W
5,810	10,915	125	799	W	W	21,668	69,036	36,203	113,675
—	—	185	670	W	W	2,801	9,529	6,806	24,005
—	—	57	346	—	—	1,575	6,258	1,632	6,603
4,635	8,813	1,175	4,252	440	1,771	15,428	57,652	44,698	155,631
W	W	—	—	—	—	1,045	2,875	1,045	2,875
W	W	253	1,675	—	—	3,318	14,390	4,861	23,328
W	W	W	W	—	—	W	W	W	W
—	—	—	—	—	—	W	W	W	W
—	—	61	930	95	428	11	180	460	4,416
W	W	—	—	—	—	696	2,795	1,287	4,241
4,440	14,762	514	2,022	—	—	7,452	34,869	24,565	116,359
—	—	W	W	—	—	3,429	19,434	3,827	20,941
2,624	10,943	1,757	8,404	W	2,016	9,993	39,968	44,165	174,262
W	W	134	484	—	—	17,457	64,126	23,855	87,682
W	W	—	—	—	—	1,382	6,418	1,382	6,418
6,378	30,867	582	5,651	634	4,079	13,590	77,531	41,122	214,912
—	—	W	W	—	—	W	W	W	W
—	—	—	—	—	—	2,487	6,719	2,487	10,935
W	W	—	—	W	W	2,619	7,667	2,619	7,667
W	W	1,164	7,769	W	W	10,235	65,930	38,524	196,188
9,388	23,938	561	3,751	1,193	6,273	17,457	62,712	60,277	195,269
W	W	3	W	1,262	5,578	1,625	6,748	2,990	12,590
—	—	—	—	—	—	1,342	6,177	1,342	6,177
W	W	503	3,796	W	W	7,161	31,675	15,258	71,874
—	—	17	W	—	—	1,491	10,766	1,521	10,766
W	W	88	841	W	W	2,194	10,215	7,327	37,248
—	—	644	3,397	148	502	8,384	27,010	20,477	71,179
—	—	—	—	—	—	510	1,397	514	1,402
67,202	215,094	18,496	99,811	6,984	33,560	257,482	1,212,160	720,939	3,091,969
11,980	33,686	159	3,068	10,637	66,071	1,710	14,474	1,710	14,474
79,182	248,780	18,655	102,87	17,621	99,631	XX	XX	722,700	3,106,400
—	—	—	—	—	—	—	—	W	18,038
1,391	5,561	W	W	—	—	3,876	22,960	7,235	40,191
—	—	—	—	—	—	—	—	W	W

TABLE 17
CRUSHED LIMESTONE AND DOLOMITE SOLD OR USED BY
PRODUCERS IN THE UNITED STATES IN 1991, BY USE

(Thousand short tons and thousand dollars)

Use	Limestone		Dolomite	
	Quantity	Value	Quantity	Value
Coarse aggregate (+ 1/2 inch):				
Macadam	3,189	13,392	122	531
Riprap and jetty stone	14,915	61,269	1,282	7,379
Filter stone	5,060	21,259	134	653
Other coarse aggregate	197	774	(¹)	(¹)
Coarse aggregate, graded:				
Concrete aggregate, coarse	67,758	300,273	8,382	42,104
Bituminous aggregate, coarse	45,110	208,579	7,867	43,572
Bituminous surface-treatment aggregate	20,436	93,027	2,589	12,094
Railroad ballast	4,556	18,216	1,112	4,392
Fine aggregate (-3/8 inch):				
Stone sand, concrete	13,311	62,338	1,296	6,988
Stone sand, bituminous mix or seal	11,439	47,634	4,447	22,532
Screening, undesignated	14,897	56,166	1,426	10,220
Other fine aggregate	119	398	—	—
Coarse and fine aggregates:				
Graded road base or subbase	115,525	428,122	10,813	47,279
Unpaved road surfacing	21,458	86,798	758	2,825
Terrazzo and exposed aggregate	1,571	9,388	4	102
Crusher run or fill or waste	23,160	88,367	2,247	8,624
Other construction materials	² 10,663	² 44,020	³ 3,855	² 20,002
Roofing granules	832	4,657	(¹)	(¹)
Agricultural:				
Agricultural limestone	15,612	74,041	2,521	20,371
Poultry grit and mineral food	2,488	26,999	W	W
Other agricultural uses	761	3,676	97	1,143
Chemical and metallurgical:				
Cement manufacture	79,182	248,780	—	—
Lime manufacture	17,974	99,632	673	3,507
Dead-burned dolomite manufacture	—	—	1,511	5,733
Flux stone	4,007	18,803	807	2,751
Chemical stone	324	1,614	W	W
Glass manufacture	297	3,009	W	W
Sulfur oxide removal	2,249	12,551	—	—
Special:				
Mine dusting or acid water treatment	726	11,250	221	1,542
Asphalt fillers or extenders	1,596	11,861	531	4,159
Whiting or whiting substitute	587	9,489	W	W
Other fillers or extenders	3,035	41,851	327	3,593
Other miscellaneous uses:				
Chemicals	557	3,120	W	W
Magnesia (dolomite)	18	30	—	—
Other uses not listed	⁴ 259	⁴ 3,672	254	3,157

See footnotes at end of table.

TABLE 17—Continued
**CRUSHED LIMESTONE AND DOLOMITE SOLD OR USED BY
 PRODUCERS IN THE UNITED STATES IN 1991, BY USE**

(Thousand short tons and thousand dollars)

Use	Limestone		Dolomite	
	Quantity	Value	Quantity	Value
Unspecified: ⁵				
Actual	163,798	748,891	7,503	32,457
Estimated	54,984	242,494	217	846
Total ⁶	722,700	3,106,400	61,000	308,600

W Withheld to avoid disclosing company proprietary data; included with "Other uses not listed."

¹Included with "Other construction materials."

²Includes other graded coarse aggregate, dam construction, drain fields, building products, pipe bedding, and waste material.

³Includes building products.

⁴Includes abrasives, paper manufacture, and refractory stone (including ganister).

⁵Includes production reported without a breakdown by use and estimates for nonrespondents.

⁶Data may not add to totals shown because of independent rounding.

TABLE 18
**CRUSHED MARBLE SOLD OR USED BY PRODUCERS IN THE UNITED
 STATES IN BY USE**

(Thousand short tons and thousand dollars)

Use	Quantity	Value
Fine aggregate (-3/8 inch):		
Stone sand, bituminous mix or seal	1	3
Coarse and fine aggregates:		
Graded road base or subbase	8	34
Unpaved road surfacing	3	8
Terrazzo and exposed aggregate	96	4,569
Other construction materials ¹	87	573
Chemical and metallurgical:		
Cement manufacture	570	2,855
Special:		
Other fillers or extenders	700	37,678
Other miscellaneous uses not listed ²	409	20,272
Unspecified: ³		
Actual	1,349	7,573
Estimated	525	9,768
Total ⁴	3,700	83,300

¹Includes crusher run or fill or waste, riprap and jetty stone, stone sand concrete, and roofing granules.

²Includes mine dusting or acid water treatment, other agricultural uses, poultry grit and mineral food, roofing granules, and whitening or whitening substitute.

³Includes production reported without a breakdown by end use and estimates for nonrespondents.

⁴Data may not add to totals shown because of independent rounding.

TABLE 19
CRUSHED GRANITE AND TRAPROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1991,
BY USE

(Thousand short tons and thousand dollars)

Use	Granite		Traprock	
	Quantity	Value	Quantity	Value
Coarse aggregate (1/2 inch):				
Macadam	695	4,181	241	757
Riprap and jetty stone	2,932	19,782	2,181	15,689
Filter stone	1,120	5,192	1,247	5,987
Other coarse aggregate	W	W	251	1,364
Coarse aggregate, graded:				
Concrete aggregate, coarse	16,202	92,629	6,589	47,054
Bituminous aggregate, coarse	16,604	107,028	5,750	47,747
Bituminous surface-treatment aggregate	3,412	22,317	1,481	10,620
Railroad ballast	8,143	39,582	3,481	18,054
Other graded coarse aggregate	—	—	31	220
Fine aggregate (-3/8 inch):				
Stone sand, concrete	2,481	14,160	1,768	18,433
Stone sand, bituminous mix or seal	5,702	27,658	1,354	8,247
Screening, undesignated	7,781	34,326	1,565	8,928
Other fine aggregate	—	—	308	2,464
Coarse and fine aggregates:				
Graded road base or subbase	24,212	111,143	20,494	103,320
Unpaved road surfacing	2,719	12,851	4,030	17,310
Terrazzo and exposed aggregates	67	395	106	811
Crusher run or fill or waste	9,323	41,039	2,818	16,337
Other construction materials	16,652	139,793	15,289	32,454
Agricultural: Poultry grit and mineral food	525	3,881	—	—
Special:				
Asphalt fillers or extenders	287	1,535	—	—
Other miscellaneous uses	36	182	131	428
Unspecified:⁵				
Actual	44,778	235,755	18,199	96,139
Estimated	10,629	50,945	6,013	32,860
Total⁶	164,300	864,400	83,300	485,200

W Withheld to avoid disclosing proprietary data; included with "Other construction material."

¹Includes roofing granules.

²Includes other coarse and fine aggregates, drain fields, roofing granules, and pipe bedding.

³Includes other agricultural uses, other fillers or extenders, and other uses not listed.

⁴Includes other fillers or extenders and other uses not listed.

⁵Includes production reported without a breakdown by end use and estimates for nonrespondents.

⁶Data may not add to totals shown because of independent rounding.

TABLE 20
CRUSHED SANDSTONE AND QUARTZITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1991,
BY USE

(Thousand short tons and thousand dollars)

Use	Sandstone		Quartzite	
	Quantity	Value	Quantity	Value
Coarse aggregate (+1/2 inch):				
Macadam	12	68	W	W
Riprap and jetty stone	700	3,701	109	474
Filter stone	241	1,526	12	66
Coarse aggregate, graded:				
Concrete aggregate, coarse	867	4,624	405	2,097
Bituminous aggregate, coarse	1,292	8,274	342	2,100
Bituminous surface-treatment aggregate	420	3,105	92	543
Railroad ballast	313	1,741	42	252
Fine aggregate (-3/8 inch):				
Stone sand, concrete	1,148	6,649	230	1,163
Stone sand, bituminous mix or seal	788	3,847	277	1,438
Screening, undesignated	621	2,143	—	—
Coarse and fine aggregates:				
Graded road base or subbase	3,493	14,884	569	1,801
Unpaved road surfaces	506	2,672	82	393
Terrazzo and exposed aggregates	44	380	—	—
Crusher run or fill or waste	898	3,304	260	910
Other construction materials	¹ 836	¹ 4,398	² 71	² 449
Chemical and metallurgical:				
Cement manufacture	274	955	W	W
Flux stone	—	—	330	2,946
Glass manufacture	440	4,761	—	—
Other miscellaneous uses	³ 20	³ 207	⁴ 2,152	⁴ 5,701
Unspecified:⁵				
Actual	4,829	21,782	1,305	6,521
Estimated	4,120	19,192	306	2,615
Total⁶	21,900	108,200	6,600	29,500

W Withheld to avoid disclosing company proprietary data: included with "Other construction materials" and "Other miscellaneous uses."

¹Includes other coarse aggregate, other graded coarse aggregate, roofing granules, and pipe bedding.

²Includes withheld amounts for coarse aggregate (1/2 inch) and dam construction.

³Includes asphalt fillers or extenders, and other uses not listed.

⁴Includes withheld amounts for chemical and metallurgical, and poultry grit and mineral food.

⁵Includes production reported without a breakdown by end use and estimates for nonrespondents.

⁶Data may not add to totals shown because of independent rounding.

TABLE 21
CRUSHED VOLCANIC CINDER AND SCORIA SOLD OR USED BY
PRODUCERS IN THE UNITED STATES IN 1991, BY USE

(Thousand short tons and thousand dollars)

Use	Quantity	Value
Coarse aggregate (+1 inch): Riprap and jetty stone ¹	50	163
Coarse aggregate, graded:		
Concrete aggregate, coarse	59	699
Bituminous aggregate, coarse	W	W
Railroad ballast	22	59
Fine aggregate (-3/8 inch): Screening, undesignated ²	153	1,272
Coarse and fine aggregates:		
Graded road base or subbase	322	1,073
Unpaved road surfacing	288	1,135
Terrazzo and exposed aggregate	263	2,822
Crusher run or fill or waste	100	352
Other construction materials ³	181	652
Agricultural: Other agricultural uses	10	59
Unspecified: ⁴		
Actual	585	3,193
Estimated	9	66
Total ⁵	2,000	11,500

W Withheld to avoid disclosing company proprietary data; included with "Other construction materials."

¹Includes filter stone.

²Includes stone sand, concrete.

³Includes other specified uses not listed.

⁴Includes production reported without a breakdown by end use and estimates for nonrespondents.

⁵Data may not add to totals shown because of independent rounding.

TABLE 22
CRUSHED MISCELLANEOUS STONE¹ SOLD OR USED BY PRODUCERS
IN THE UNITED STATES IN 1991, BY USE

(Thousand short tons and thousand dollars)

Use	Quantity	Value
Coarse aggregate (+1/2 inch):		
Macadam	117	423
Riprap and jetty stone	480	2,612
Filter stone	56	249
Other coarse aggregate	50	142
Course aggregate, graded:		
Concrete aggregate, coarse	530	2,281
Bituminous aggregate, coarse	1,229	5,845
Bituminous surface-treatment aggregate	550	1,866
Railroad ballast	407	2,566
Fine aggregate (-3/8 inch):		
Stone sand, concrete	329	1,628
Stone sand, bituminous mix or seal	322	1,412
Screening, undesignated	654	3,107
Coarse and fine aggregates:		
Graded road base or subbase	4,101	15,679
Unpaved road surfacing	703	4,107
Terrazzo and exposed aggregate	56	445
Crusher run or fill or waste	551	3,388
Other coarse and fine aggregates	82	360
Other construction materials ²	2,030	9,591
Agricultural: Poultry grit and mineral food ³	142	272
Chemical and metallurgical: Cement manufacture	3,215	7,755
Special:		
Other fillers or extenders	419	2,239
Other miscellaneous uses ⁴	13	84
Unspecified:⁵		
Actual	16,876	103,401
Estimated	4,452	20,211
Total⁶	37,400	189,700

¹Includes marl, shell, slate, and other stone.

²Includes roofing granules, and lightweight aggregate (slate).

³Includes other agricultural uses.

⁴Includes abrasives and other specified uses not listed.

⁵Includes production reported without a breakdown by end use and estimates for nonrespondents.

⁶Data may not add to totals shown because of independent rounding.

TABLE 23
**CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1991,
 BY REGION AND METHOD OF TRANSPORTATION**

(Thousand short tons)

Region	Truck	Rail	Water	Other	Not transported	Not specified	Total ¹
Northeast:							
New England	7,835	134	—	—	2,404	10,010	20,383
Middle Atlantic	72,696	1,631	3,760	2,981	10,238	32,824	124,130
Midwest:							
East North Central	103,128	4,415	18,754	1,136	22,827	71,378	221,639
West North Central	54,271	1,556	6,282	—	6,360	45,495	113,963
South:							
South Atlantic	131,167	15,508	4,521	2,323	14,340	86,205	254,064
East South Central	66,651	3,515	12,000	2,898	11,421	25,345	121,830
West South Central	41,773	12,268	1	3,725	9,771	55,345	122,883
West:							
Mountain	13,730	493	—	530	3,667	13,774	32,194
Pacific	44,716	1,048	852	4,551	14,009	26,614	91,790
Total¹	536,000	40,600	46,200	18,100	95,000	367,000	1,102,900

¹Data may not add to totals shown because of independent rounding.

TABLE 24
**NUMBER OF CRUSHED AND BROKEN STONE OPERATIONS AND PROCESSING PLANTS IN THE
 UNITED STATES IN 1991, BY STATE**

State	Mining operations on land				Dredging operations	Total active operations
	Stationary	Portable	Stationary and portable	No. plants or unspecified		
Alabama	42	2	—	1	—	45
Alaska	4	5	3	5	—	17
Arizona	17	9	—	10	—	36
Arkansas	33	10	2	5	—	50
California	66	35	6	18	—	125
Colorado	12	13	4	5	—	34
Connecticut	17	1	1	—	—	19
Florida	46	29	9	9	6	99
Georgia	73	2	1	3	—	79
Hawaii	14	7	1	5	—	27
Idaho	10	27	2	5	—	44
Illinois	95	61	6	7	—	169
Indiana	72	3	3	4	—	82
Iowa	26	209	2	13	—	250
Kansas	27	85	2	6	—	120
Kentucky	75	7	—	4	—	86
Louisiana	1	—	—	—	4	5
Maine	7	3	—	—	—	10
Maryland	18	8	—	1	—	27
Massachusetts	11	9	2	2	—	24
Michigan	18	10	—	8	2	38
Minnesota	8	32	2	1	—	43
Mississippi	3	2	—	—	—	5
Missouri	94	74	12	4	—	184
Montana	7	4	1	1	—	13
Nebraska	8	3	—	2	—	13
Nevada	6	3	1	—	—	10
New Hampshire	7	3	—	—	—	10
New Jersey	17	1	6	—	—	24
New Mexico	21	17	1	2	—	41
New York	73	9	9	1	—	92
North Carolina	79	6	5	3	—	93
North Dakota	—	—	—	1	—	1
Ohio	93	7	5	3	1	109
Oklahoma	46	11	6	3	—	66
Oregon	45	91	5	16	—	157
Pennsylvania	134	19	13	22	—	188
Rhode Island	6	—	—	—	—	6
South Carolina	27	2	1	2	—	32
South Dakota	7	2	—	2	—	11
Tennessee	106	4	6	4	—	120
Texas	70	50	11	23	—	154
Utah	7	24	2	3	—	36
Vermont	7	9	1	5	—	22
Virginia	93	—	5	4	—	102
Washington	26	69	4	30	1	130

TABLE 24—Continued
**NUMBER OF CRUSHED AND BROKEN STONE OPERATIONS AND PROCESSING PLANTS IN THE
 UNITED STATES IN 1991, BY STATE**

State	Mining operations on land				Dredging operations	Total active operations
	Stationary	Portable	Stationary and portable	No. plants or unspecified		
West Virginia	30	9	1	5	—	45
Wisconsin	26	131	—	23	—	180
Wyoming	6	8	—	—	—	14
Total	1,736	1,125	141	271	14	3,287

TABLE 25
U.S. EXPORTS OF CRUSHED STONE IN 1991, BY DESTINATION

(Short tons)

Destination	Limestone for cement manufacturing	Other	Chalk, crude	Granules, chippings	Total ¹
North America:					
Bahamas	4	—	—	3	8
Bermuda	228	—	—	37	266
Canada	2,239,466	799	4,819	131,841	2,376,925
Dominican Republic	3	—	—	23	26
El Salvador	24	—	—	—	24
Mexico	3,800	—	45	5,348	9,193
Netherlands Antilles	—	—	—	6	6
Nicaragua	—	—	—	2	2
Panama	40	—	45	—	85
Trinidad and Tobago	53	—	18	11	82
Total¹	2,243,619	799	4,927	137,272	2,386,617
South America:					
Brazil	—	28	—	—	28
Columbia	—	—	4	—	4
Suriname	474	—	—	—	474
Venezuela	134	22	35	174	366
Total¹	608	50	40	174	872
Europe:					
France	—	2,682	55	—	2,737
Germany, Federal Republic of	—	3,153	7	5,297	8,456
Italy	—	75	24	7	106
Netherlands	—	952	—	—	952
Norway	—	93	—	—	93
Switzerland	—	90	—	—	90
Commonwealth of Independent States	—	1	—	—	1
United Kingdom	1,477	188	2	—	1,668
Total¹	1,477	7,234	87	5,303	14,102
Asia:					
China	186	—	2	—	188
Hong Kong	104	—	—	211	314
Indonesia	—	8	—	—	8
Japan	3,463	5,975	289	869	10,595
Korea, Republic of	4	245	23	42	314
Malaysia	—	137	35	—	172
Phillipines	291	—	—	—	291
Singapore	—	—	—	20	20
Taiwan	1	370	249	138	758
Thailand	—	37	—	19	56
Total¹	4,050	6,771	599	1,297	12,712
Oceania: Australia	—	—	143	23	166

See footnotes at end of table.

TABLE 25—Continued
U.S. EXPORTS OF CRUSHED STONE IN 1991, BY DESTINATION

(Short tons)

Destination	Limestone for cement manufacturing	Other	Chalk, crude	Granules, chippings	Total ¹
Middle East and Africa:					
Angola	88	—	—	—	88
Egypt	—	—	—	93	93
Saudi Arabia	—	—	25	117	142
Total	88	—	25	210	323
Grand total¹	2,249,842	14,855	5,821	144,279	2,414,800
Total value (thousand)	9,942	15,146	1	7,913	33,003

¹Data may not add to totals shown because of independent rounding.

Source: U.S. Bureau of the Census.

TABLE 26
**U.S. IMPORTS OF CRUSHED STONE AND CALCIUM CARBONATE
 FINES, BY TYPE**

(Thousands short tons and thousand dollars)

Type	1990		1991	
	Quantity	C.i.f. value	Quantity	C.i.f. value
Crushed stone and chips:				
Limestone ¹	2,358	12,439	3,667	21,239
Limestone for flux or cement manufacturing	2,176	16,587	1,781	13,498
Quartzite	10	845	3	485
Other	425	4,571	275	2,676
Total	4,969	34,442	5,726	37,898
Calcium carbonate fines:²				
Natural chalk	(³)	94	(³)	47
Calcium carbonates—other chalk	3	770	2	704
Total	3	864	2	751
Grand total	4,972	35,310	5,728	38,649

¹Excludes limestone for cement manufacturing.

²Excludes precipitated calcium carbonate.

³Less than 1/2 unit.

⁴Data do not add to total shown because of independent rounding.

Source: U.S. Bureau of the Census.

FIGURE 1
**PRODUCTION OF CRUSHED STONE IN THE UNITED STATES IN 1991,
 BY GEOGRAPHIC REGION**

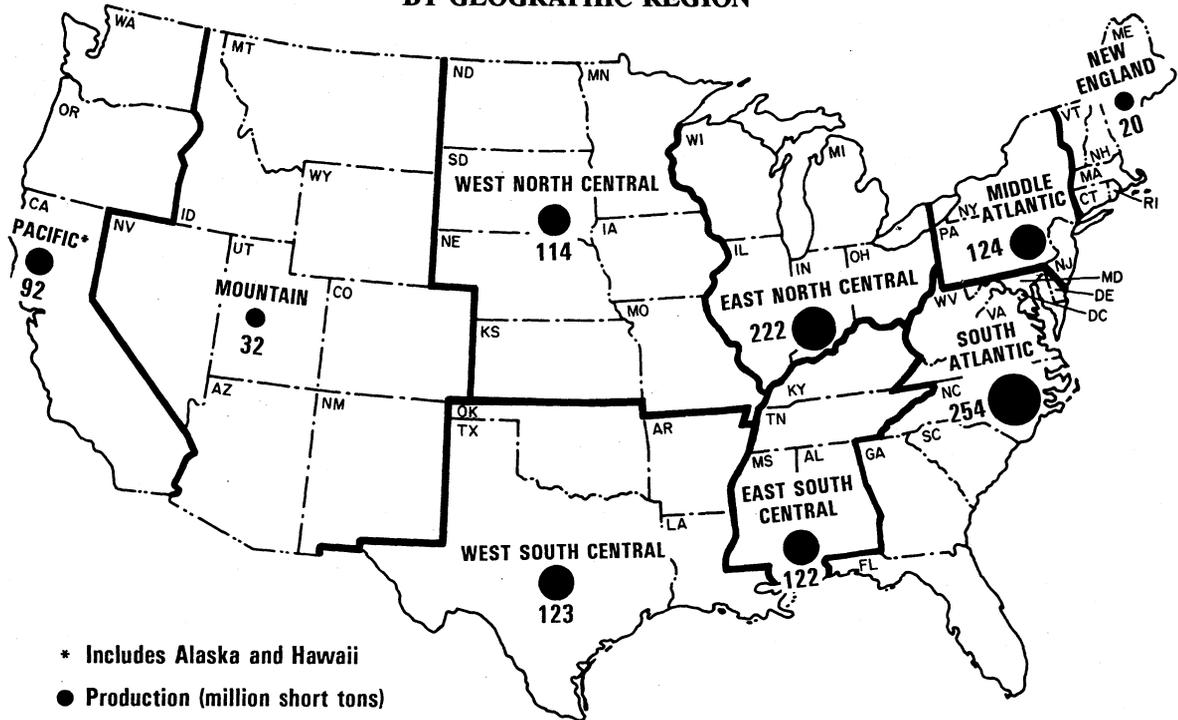
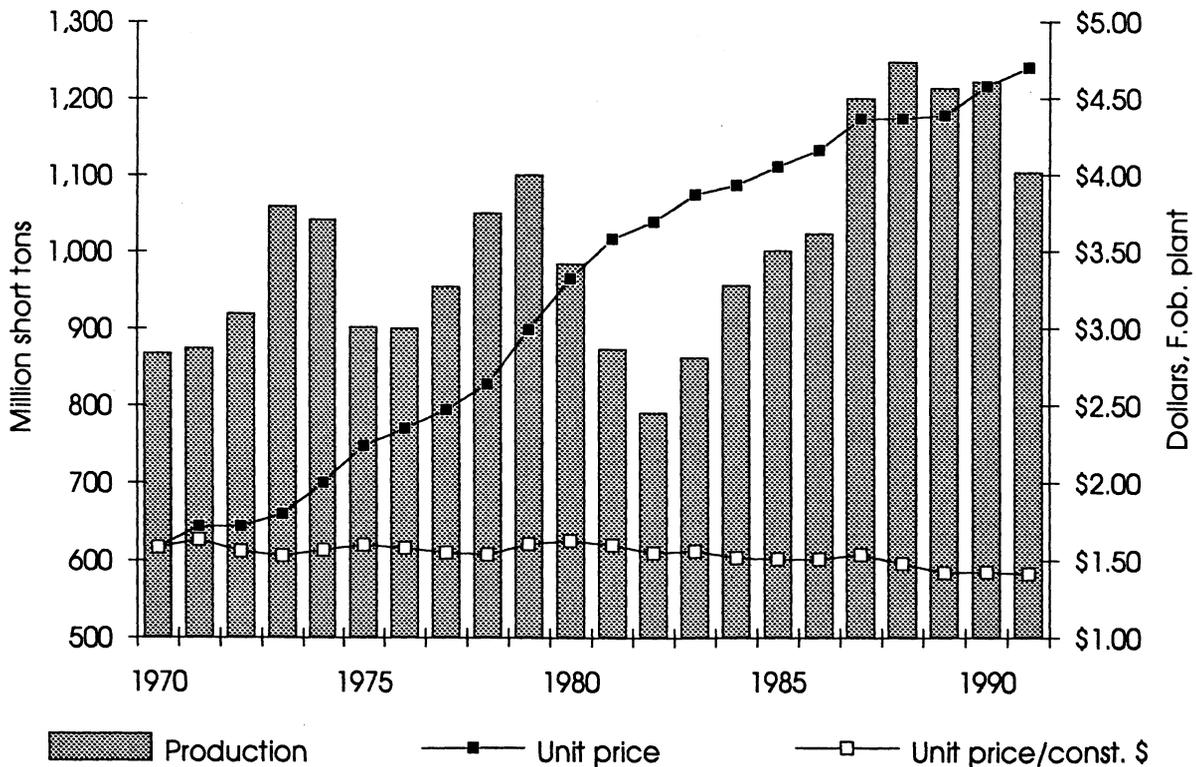


FIGURE 2
**PRODUCTION AND UNIT PRICE IN ACTUAL AND 1970 CONSTANT DOLLARS
 OF CRUSHED STONE IN THE UNITED STATES**



DIMENSION STONE

By Harold A. Taylor, Jr.

Mr. Taylor, a physical scientist with 26 years of industry, Federal Government, and U.S. Bureau of Mines experience, has been the commodity specialist for dimension stone since 1981. Domestic survey data were prepared by Robin Richardson, statistical assistant.

Production of dimension stone increased slightly to 1.14 million short tons valued at \$197 million. More than one-half of the dimension stone produced was granite. Limestone, marble, sandstone, and slate were also produced.

Exports of dimension stone increased 20% in value to \$65 million. The value of dimension stone imports for consumption decreased 19% to \$475 million, equivalent to 241% of the value of domestic production.

DOMESTIC DATA COVERAGE

Domestic production data for dimension stone are developed by the U.S. Bureau of Mines from voluntary surveys of U.S. producers of rough and finished dimension stone. Of the 368 dimension stone operations surveyed for 1991, including those that were idle, 328, or 89%, responded, representing 96% of the estimated value shown in table 1. Production data for nonrespondents were estimated using preliminary production reports, adjusted prior years' production levels, and employment data. (See table 1.)

BACKGROUND

Definitions, Grades, and Specifications

Dimension stone is a natural rock material that has been selected, trimmed, or cut to specified or indicated shapes or sizes, with or without one or more mechanically dressed surfaces. This includes rough stone, rubble, ashlar, blocks, panel, and curvilinear shapes. Finished surface requirements may vary from a controlled fractured surface to

ground and polished. The most prominent required qualities of dimension stone are strength, toughness, hardness, and resistance to environmental damage. Color and grain structure contribute largely to price and marketability. The principal types of dimension stone used in construction are granite, marble, limestone, sandstone, and slate.

Stone classification by type in the dimension stone industry is somewhat ambiguous and does not correspond in some respects with the same terms used in mineralogical rock descriptions. The U.S. Bureau of Mines generally accepts the classification reported by producers. Granite includes all feldspathic crystalline rocks of predominantly interlocking texture and with mineral grains visible to the naked eye; these include igneous and metamorphic rocks, including quartz diorites, syenites, quartz porphyries, gabbros, anorthosites, and gneisses. White, gray, black, pink, and red are the common colors for granite, but greens, browns, and other shades are produced in some localities.

Limestone includes dolomitic types as well as calcitic. The latter contains less than 5% magnesium carbonate ($MgCO_3$). Dolomitic limestone contains 5% to 40% $MgCO_3$. Marble is a recrystallized (metamorphosed) limestone containing grains of calcite or dolomite or both. In commercial usage, it is any calcareous crystalline rock or serpentine, a hydrous magnesium silicate, capable of taking a polish. Travertine is a type of marble similar to onyx except that it is precipitated from warm or hot water; it has a banded cellular structure and contains cavities up to one-half inch in

width that are lined with microstalactites. Dark green serpentines are classified as marble in the industry because they are often crisscrossed with marblelike veinlets of lighter materials, chiefly calcite or dolomite, and because of their ability to take a high polish.

Commercial sandstone is a sedimentary rock consisting mostly of quartz, sometimes with feldspar, or rock fragments of clastic texture bonded by silica, clay, calcite, or iron oxide. Bluestone is a dense, hard, fine-grained feldspathic sandstone that splits easily along a plane into thin, smooth slabs. It is commonly dark or slate gray in color, and its name no longer has color significance. Brownstone is a feldspathic sandstone of brown reddish-brown color caused by abundant interstitial iron oxide. Flagstone may be either a sandstone or a slate that splits into large, thin slabs.

Quartzite is a metamorphic equivalent of sandstone that has been firmly cemented by secondary silica or by recrystallization so that it is essentially homogeneous and fractures through rather than around the original sand grains.

Slate is a fine-grained metamorphic rock derived from shale, siltstone, or claystone. It has prominent cleavage that is oriented independently from the original sedimentary bedding. Mineral constituents are quartz, mica, sericite, or chlorite with assorted minor accessories. Shale is composed mostly of original clay minerals, and cleavage is parallel to the bedding.

Traprock is a commercial term for all dark, igneous rocks too fine in grain size to be called black granite. In addition to extrusive flow rocks such as basalt, andesite, or dacite, traprock includes

intrusive igneous rocks such as diabase, diorites, gabbros, pyroxenites, amphibolites, and peridotites.

Miscellaneous stones used for dimension purposes include schist, scoria, soapstone, wollastonite, argillite, and many others.

Geology-Resources

Domestic resources of most types of dimension stone used in construction are practically unlimited. There is considerable interstate transportation of certain types of stone such as Indiana limestone, Georgia marble and granite, and Vermont granite, marble, and slate. A lack of deposits of certain specific varieties of dimension stone especially noted for their aesthetic qualities in architecture and artifact manufacture is an important cause of importation of these varieties; for example, brightly colored marbles from Italy.

Technology

Mining.—Present mining methods range from antiquated and very inefficient, which is rather uncommon nowadays, to modern and technically superior. Quarrying methods include use of various combinations of diamond saws, wire saws, diamond wire saws, chain saws, channeling machines, drilling machines, wedges, and broaching tools. The choice of equipment depends on the type of dimension stone, size and shape of deposit, production capacity, labor costs, economics, and management investment attitudes.

Little blasting is done in the mining of dimension stone. Blocks cut from the face are sawed or split into smaller or thinner blocks for ease in transportation and handling and taken to processing plants, commonly at the quarry site, for final cutting and finishing operations.

Processing.—Stone-sawing equipment includes large circular saws 10 feet or more in diameter, usually with diamond inserts; diamond circular saws of smaller size; and reciprocating diamond-bladed or

loose-abrasive gang saws for multiple cuts. Various types of diamond and other equipment are used for smoothing, polishing, edging, and decorating the finished stone products. (See table 2.)

Economic Factors

The depletion allowance for dimension stone is 14%. Dimension stone quarries are generally in mountainous or hilly areas remote from areas of dense population. Because land use for other purposes is limited, the cost of land is reasonable.

Transportation costs for dimension stone are high because of its weight and because special handling methods are required to prevent damage to the finished stone. A single stone panel broken in transit not only results in the loss of the many employee-hours of skilled labor required to produce it, but also can cause construction delays that are even more costly. Nevertheless, dimension stone is routinely shipped long distances by motor and rail freight, and special domestic varieties are shipped by ocean freight to foreign countries.

Operating Factors

Environmental requirements vary from State to State and are often a cause of conflict between State or local governments and the quarry operators.

Stone primary and waste products are not toxic, nor are the supplies utilized in their production. However, sufficient exposure to silica-rich stone dust can cause silicosis.

The approximate number of employees in the dimension stone industry by stone kind are granite, 9,600; limestone, 1,100; marble, 1,500; slate, 950; and sandstone and other dimension stone, 850. Of the total 14,000, about 3,100 are employed in quarrying and approximately 10,900 in finishing operations. Major States for employment were Georgia with 2,100 employees, Vermont with 1,700, Minnesota with 1,250, North Carolina with 850, Texas with 700, and Indiana with 650.

Fuel is used to power quarrying equipment, and electricity is used for sawing and finishing. Water is used in some quarries to cool equipment such as chain saws and in sawing and finishing plants to cool the equipment; water consumption is relatively minimal in all instances.

ANNUAL REVIEW

Production

Dimension stone was produced by 185 companies at 279 quarries in 35 States, including Puerto Rico. Leading States, in order of tonnage, were Indiana, Georgia, and Vermont, together producing 40% of the Nation's total. Of the total production by tonnage, 51% was granite, 28% was limestone, 11% was sandstone, 3% was slate, 4% was marble, and the remaining 3% was miscellaneous stone. Miscellaneous stone included argillite, schist, soapstone, and traprock (basalt). Leading producing companies, in terms of tonnage, were Cold Spring Granite Co., principally in California, Minnesota, South Dakota, and Texas; Rock of Ages Corp. in New Hampshire and Vermont; and Fletcher Granite Co., Inc., in Massachusetts and New Hampshire.

Granite.—Dimension granite includes all coarse-grained igneous rocks. Production decreased 8% to 585,300 tons and decreased 16% in value to \$97.8 million. Granite was produced by 58 companies at 104 quarries in 19 States. Georgia continued to be the leading State, producing 30% of the U.S. total, followed by Vermont and Massachusetts. These three States together produced more than 54% of the U.S. total. Cold Spring Granite, Rock of Ages, and Fletcher Granite were the leading producers and accounted for 47% of U.S. production by tonnage.

Limestone.—Dimension limestone includes bituminous, dolomitic, and siliceous limestones. It was produced by 33 companies at 39 quarries in 12 states. Indiana, the leading State, was followed

by Wisconsin and Texas. Leading producers were Indiana Limestone Co. Inc., Independent Limestone Co., and Victor Oolitic Stone Co. The top three companies accounted for 31% of U.S. output.

Marble.—Dimension marble includes certain hard limestones, travertines, and any other calcareous stone that can be polished. Dimension marble was produced by 13 companies at 15 quarries in 11 States, including Puerto Rico. Colorado, Georgia, and Vermont, in order of tonnage, were the three leading States, accounting for approximately 73% of U.S. output. Leading producers were Colorado Yule Marble Co., Georgia Marble Co., and Vermont Marble Co. The top three companies accounted for 72% of U.S. output.

The major news in marble this year was the addition of a new domestic producer and the major expansion of two almost-new producers. The production of the Colorado Yule Marble Co. rapidly expanded as it came more fully on-stream. The product will be used in the new Denver Airport. Sizable amounts of rough blocks are being exported to Italy and Japan.

Dixie Marble, Inc. has opened a quarry near Sylacauga, AL, for Alabama marble. The quarry is producing a white, a gray, and two white with gray veining marbles. Diamond wire saws and diamond belt saws are being used in the quarry to cut out the rough blocks. Reserves will last 150 years at the present rate of quarrying. The firm is also producing four shades of Tennessee marble and buying rough blocks of several colors of Arkansas marble. These marbles are being made into tile by the Armstar plant in Lenoir City, TN. The firm is planning to add some gangsaws and a finishing plant for tiles and slabs later. This represents a substantial increase in the number of colors of domestic marbles currently available, particularly counting the new Puerto Rican marbles.

The Puerto Rican operations of Marmoles Vassco, Inc., of Ponce, Puerto Rico, really hit their stride this year, now

that the new equipment is almost all beyond the startup phase. The quarrying operation presently supplies a number of colors, to which will be added a black marble when a new quarry comes on-stream. The marble is quarried by diamond wire saws. The finishing plant has a capacity of 120,000 square feet per month of tile. Thin (5/8 inch) bush-hammered tile is also produced. The firm also can produce structural items such as window sills, thresholds, and risers, plus tables and countertops. It now has 80 employees, up from 7 in 1988. The firm is considering exporting rough blocks, perhaps to Italy.

Sandstone.—Dimension sandstone includes calcareous- and siliceous-cemented sandstones or conglomerates. Quartzite, which is also included, may be described as any siliceous-cemented sandstone. It was produced by 30 companies at 55 quarries in 16 States. The leading three States were, in order of volume, Ohio, Arizona, and New York. Western State Stone Co., Inc., Briar Hill Stone Co., and Waller Bros. Stone Co. were the leading producers and accounted for 44% of U.S. production. In addition to the quantities shown in table 7, dimension quartzite totaled 16,766 tons worth \$1,340,000.

Slate.—Dimension slate was produced by 20 companies at 25 quarries in 7 States. The two leading States, Vermont and Pennsylvania, in order of volume, accounted for 69% of U.S. output. The top three producers, A. Dally and Sons Inc., LeSueur-Richmond Slate Co. Inc., and Alfred McAlpine Inc., accounted for an estimated 44% of U.S. output by volume.

Miscellaneous Stone.—Miscellaneous dimension stone, including traprock, was produced by five companies from six quarries in four States and totaled 15,643 tons value at \$1,351,000. (See tables 3, 4, 5, 6, and 7.)

Consumption and Uses

Dimension stone was marketed over wide areas. Industry stockpiles were not monitored, and production during 1989 was assumed to equal consumption.

Consumption of domestic dimension stone increased slightly to 1.14 million tons valued at \$197.1 million. Ashlars and partially squared, dressed pieces were 21% of the total value of consumption, followed by rough monumental stone with 15%; slabs and blocks for building and construction with 14%; dressed monumental stone with 14%; and other uses, 24%.

Of the total consumption of domestic granite, 31% by value was rough monumental stone, 18% was dressed monumental stone, 17% was ashlar and partially squared pieces, and 17% was curbing.

Consumption of domestic limestone totaled 316,982 tons valued at \$45.4 million, of which 43% was ashlar and partially squared pieces, 25% was rough blocks for building and construction, and 19% by value was dressed slabs and blocks for building and construction. The change in ashlar from previous years reflects shifts in building practice to veneer and a shift in reporting.

Limestone tile is an important new product that is rapidly gaining popularity. For several years now, tiles made out of hard limestone have sometimes been used as substitutes for other stones, particularly granite tile. These tiles (or slabs) have sometimes been domestic, but more commonly were French or Spanish limestones. They were used in applications where granite or marble are customarily used. Now tile of softer limestones are being made and sold. Specific applications known include some flooring areas not subject to heavy traffic or grit-bearing footwear. (See tables 8, 9, 10, 11, 12, and 13.)

In a long-enduring trend before 1980, building dimension stone was replaced to a large extent by concrete, glass, brick, stainless steel, aluminum, porcelain-enameled steel, and plastics. These materials are used in the manufacture of modern mass-produced building modules

and precast building panels. The installed cost of many of these alternate materials has been lower than that of stone. Since 1980, stone has been increasingly preferred for more dignified buildings where its architectural adaptability, permanence, and prestige are of prime importance. A movement back to stone has occurred because of the greater impact of rising energy costs on these substitutes. Resin-bonded stone panels made from stone chips are becoming an important substitute for dimension stone.

Slate has to meet competition from many sources. As a roofing material, alternates such as sheet metal, wood shingles, asbestos-cement shingles, and tile are available. For blackboards, it competes with colored glass, porcelain-enameled steel, and special painted surfaces.

Prices

The average price for dimension stone increased to \$173 per ton, down slightly from \$177 in 1990.

Foreign Trade

Exports.—Exports of dimension stone, more than 50% of which was granite, increased 21% in value.

Imports.—Imports for consumption of dimension stone decreased 19% in value to \$475 million, mostly because of decreases in imports of several major categories of dimension stone, particularly marble slabs, for the second year in a row. Imports of dressed marble slabs, mostly from Italy, decreased 50% to \$74 million. On a value basis, marble accounted for 50% of imports, followed by granite at 33%. (See tables 14, 15, 16, and 17.)

World Review

Dimension stone is quarried in the great majority of nations in the world. As usual, Italy produced about one-half of the world production. The major importing countries were the United

States and Japan; and for rough stone, also Italy. Other significant producers were Brazil, China, Finland, India, Norway, Portugal, Spain, Sweden, Turkey, and the United States.

A major review of world dimension stone markets appeared this year. The statistics are of particular interest. For example, Italy accounted for 25.9% of world dimension stone exports in 1990, Spain, 8.6%; India, 7.4%; the Republic of South Africa, 7.2%; China, 5.9%; Republic of Korea, 5.5%; Portugal, 5.3%; and Brazil, 5.2%. When world dimension stone consumption is considered by application, flooring applications account for 35.2%. In addition, external building facing accounted for 22.8%, funeral products (monumental) for 14.7%, stairs and halls for 7.2%, structural works for 7.2%, internal building facing for 5.2%, and the balance in other applications. The outlook stated was positive, considering the trend toward stone and away from competing materials, changing technology leading to new uses, and supply restrictions in many countries outside North America and Western Europe caused by increased pressure to reclaim closed quarries.¹

A major review of world slate markets appeared in the same source. The increased interest in dimension stone in the 1980's has also helped the slate industry. At the same time, many firms have undertaken considerable modernization programs, often involving saws. While much more of the production is done by machinery, roofing slate and most other products are still split by hand. Spain produces about 440,000 to 500,000 tons of roofing slate per year, of which 30,000 tons is consumed domestically. France produces about 50,000 tons of roofing slate per year, the United Kingdom about 39,000 tons, and the Federal Republic of Germany about 20,000 tons. Production in all these countries expanded to a marked degree during the 1980's. The importance of Brazil, China, and India is increasing in world slate markets. Usage of waste slate is much higher in Europe

than America, such as in road aggregate, roofing granules, and fillers.²

Finland.—A thorough review of the Finnish dimension stone industry recently indicated that it was steadily expanding and doing quite well, particularly granite and soapstone. The granite is mostly quarried in the area surrounding Helsinki, particularly to the west. Most of the soapstone is quarried near Juuka, about 200 miles northeast of Helsinki. The largest granite producer is Finska Stenindustri Ab, and the largest soapstone producer is Suomen Vuolukivi Oy (Tulikivi). The great majority of the granite is exported, almost all as rough blocks. Most of the soapstone is made into stoves, fireplaces, and architectural products and used domestically. The rest of the soapstone is exported as these same finished products. The granite industry is opening new quarries that will broaden the range of colors available. The soapstone industry will continue to respond to the growing domestic demand as well as the export demand.³

Hungary.—Centurion Mining PLC of London and the Hungarian Investment Co. Ltd. have jointly and equally bought a one-half interest in state-owned Kofargo. Kofargo will now be only one-half state-owned and will be subdivided into Pannon Marble Industries and Renaissance Stone Masonry Co. Pannon Marble's Sutto Div. will own and operate three red marble quarries, five travertine quarries, and four finishing plants for slab and tile. Pannon's Siklos Div. will operate three quarries that produce pink, yellow, cream, green, and gray marbles and a limestone and operate a finishing plant for tile. Renaissance Stone Masonry will operate a finishing plant for ashlar, architectural products, and sculptural work. It will also provide masonry and renovation expertise.

India.—Exports of Indian dimension stone have grown rapidly in recent years: in 1986-87 it was 600 million Rupees and in 1989-90 it was 1,520 million Rupees (1,470 of this being granite). More than

20 different types of granite are produced and exported as rough block, polished slab, tile, and monuments. Polished marble slabs and tiles valued at 20 million Rupees are exported. Slate exports are growing but are still very small. Granite is quarried mostly in Andhra Pradesh, Karnataka, and Tamil Nadu States, and marble is quarried mostly in Rajasthan.

Mexico.—Marmoles Muguero S.A. has built a 70,000-square-foot-per-month-capacity finishing plant, mostly for tile, in Durango. The tile will be available in many sizes and several patterns and styles, such as octagon and hexagon. The plant will process volcanic tuff, called Sierra Stone, from the firm's five quarries in or near the Sierra Madre Mountains. The tuff comes in 12 colors, mostly pastels.

MTC has just completed a finishing plant in Zacatecas for onyx. It has a capacity of 190,000 square feet of tile and 70,000 square feet of slab per month. The firm has five onyx quarries, two of which are presently operating, all of which use diamond wire saws.

Some other firms have finishing plants for marble and/or granite. The Industrias Petrus Group has six operating quarries and several plants; one plant, belonging to Granitos Naturales S.A., makes granite tiles and slabs in Nuevo Laredo, and one, belonging to Industrias del Travertino S.A., makes travertine tile. This group produces 3.6 million square feet of marble tile, 1.2 million square feet of marble slab, 600,000 square feet of granite tile, and 600,000 square feet of granite slabs per year. Terramar Mosaicos SA has a marble tile and slab plant in Puebla. Fachadas y Monumentos S.A. de C. V. has three operating quarries and several plants—one plant makes marble tile and slab in Monterrey; one, belonging to J. G. Marmol S.A. de C. V., makes marble tile in Puebla; and one, belonging to Marmorey S.A. de C. V., makes marble tile in Torreon. The latter group produces 1.4 million square feet of tile, 350,000 square feet of slab, and 750,000 square feet of cut-to-size pieces per year.

Namibia.—The only dimension stone production of any importance is for marble, which totaled 13,850 tons in 1989. Some other stone was produced; for example, limestone and granite. The marble is mostly quarried in the Karibib area (white, yellow, brown, and gray mostly) and in the Swakopmund area (verde antique). Sizable amounts of white and light-colored limestone is quarried south of Aus. Granite is also quarried in the Karibib and Swakopmund areas and in the Okahandja and Spitzkoppe areas.

Spain.—The Ingemar group of dimension stone producers has formed another firm, Ingemarto S.A., to run a new plant that has 17 gangsaws and a granite tile line. The plant, near Toledo, will serve 11 company-owned granite quarries in central and western Spain. The other Ingemar firms are in northernmost Spain, at Usurbil and Guitiriz. The group produces 18 million square feet of granite slab, 0.5 million square feet of granite tile, 4.5 million square feet of marble slab, plus cut-to-size items, limestone, and other products.

Current Research

Two comprehensive articles on stone anchoring systems appeared in the same issue of a major trade journal. Selecting the correct anchoring system is important in preventing failure of the stone cladding of a building. One article covered the Cygnus Wall System, the Slotlok Fastener System, Halfen brackets, Heckmann Building ties and anchors, and Frimeda anchors. The other article covered continuous anchors, such as an aluminum anchor with bearing point, an aluminum offset anchor, an aluminum gravity anchor, an intermediate anchor in noncontinuous slot, a soffit panel with marble liner, a frame with continuous aluminum anchors, and a noncontinuous aluminum-base support. It also recommended what metal-to-metal contacts to use to avoid galvanic corrosion.⁴

OUTLOOK

Projected demand for dimension granite totaled 1.5 million tons for 1995 and 2.2 million tons for the year 2000. Demand for dimension marble totaled 400,000 tons for 1995 and 600,000 tons for the year 2000. Demand for dimension limestone totaled 350,000 tons for 1995 and 390,000 tons for the year 2000, while demand for slate ought to be 35,000 tons in 1995 and 37,000 tons in the year 2000. This slow rate reflects a major drop in the market for building stone in 1989-93 and a welcome recovery later in the 1990's. Certain segments will continue to grow rapidly, such as the uses in kitchens and bathrooms. The supply will be adequate and is likely to shift in favor of domestic producers.

¹Harries-Rees, K. Dimension Stone Review—The New "Stone Age." *Ind. Miner.* (London), No. 290, Nov. 1991, pp. 43-52.

²_____. Slate Market Split-Niche Develops for Prestige Products. *Ind. Miner.* (London), No. 284, May 1991, p. 44-55.

³Benbow, J. Finland's Mineral Industry—Turning to Stone. *Ind. Miner.* (London), No. 283, Apr. 1991, pp. 19-37.

⁴Zielinski, B. Today's Stone Anchoring Systems. Merrigan, M. M. Continuous Anchors for Thin Stone Slab Veneer. *Dimensional Stone*, v. 7, No. 7, July-Aug. 1991, pp. 27-36, 38-41, 45.

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TABLE 1
SALIENT U.S. DIMENSION STONE STATISTICS

(Thousand short tons and thousand dollars)

	1987	1988	1989	1990	1991
Sold or used by producers	*1,179	*1,159	*1,238	*1,186	1,139
Value	*\$190,117	*\$207,489	*\$210,878	*\$209,601	\$197,142
Exports (value)	\$20,470	*\$42,668	\$34,610	\$54,019	\$64,947
Imports for consumption (value)	\$439,278	\$517,835	\$525,052	\$586,243	\$475,056

*Estimated. Revised.

TABLE 2
U.S. IMPORT DUTIES ON DIMENSION STONE

Tariff item	HTS No.	Most favored nation (MFN)	Non-MFN
		Jan. 1, 1992	Jan. 1, 1992
Slate: Rough blocks or slabs	2514.00	3.7% ad valorem	25% ad valorem.
Rough blocks or slabs of marble, travertine, and other calcareous monumental or building stone:	2515		
Marble and travertine:			
Crude or roughly trimmed	2515.11	\$3.46 per cubic meter	\$22.95 per cubic meter.
Marble, merely cut	2515.12.10	2.1% ad valorem	13% ad valorem.
Travertine, merely cut	2515.12.20	6% ad valorem	50% ad valorem.
Other calcareous stone, alabaster	2515.20.00	6% ad valorem	50% ad valorem.
Rough blocks or slabs of granite, porphyry, basalt, sandstone, and other monumental or building stone:	2516		
Granite:			
Crude or roughly trimmed	2516.11.00	Free	\$8.83 per cubic meter.
Merely cut	2516.12.00	4.2% ad valorem	60% ad valorem.
Sandstone:			
Crude or roughly trimmed	2516.21.00	Free	\$5.30 per cubic meter.
Merely cut	2516.22.00	6% ad valorem	50% ad valorem.
Other monumental or building stone	2516.90.00	6% ad valorem	50% ad valorem.
Setts, curbstones, and flagstones	6801.00.00	4.2% ad valorem	60% ad valorem.
Worked monumental or building stone	6802		
Tiles and cubes under 7cm square, granules	6802.10.00	6.9% ad valorem	40% ad valorem.
Other stone and articles with a flat or even surface:			
Marble, travertine and alabaster:			
Travertine	6802.21.10	6% ad valorem	50% ad valorem.
Other	6802.21.50	2.1% ad valorem	13% ad valorem.
Other calcareous stone	6802.22.00	6% ad valorem	50% ad valorem.
Granite	6802.23.00	4.2% ad valorem	60% ad valorem.
Other stone	6802.29.00	7.5% ad valorem	30% ad valorem.
Other:			
Marble, travertine, and alabaster:			
Marble:			
Slabs	6802.91.05	2.8% ad valorem	15% ad valorem.
Other	6802.91.15	6% ad valorem	50% ad valorem.
Travertine:			
Articles of subheading 6802.21.10 that have been dressed or polished, but not further worked	6802.91.20	6% ad valorem	50% ad valorem.
Other	6802.91.25	5.3% ad valorem	40% ad valorem.
Alabaster	6802.91.30	5.3% ad valorem	50% ad valorem.
Other calcareous stone	6802.92.00	6% ad valorem	50% ad valorem.
Granite	6802.93.00	4.2% ad valorem	60% ad valorem.
Other stone	6802.99.00	6.5% ad valorem	40% ad valorem.
Worked slate and articles:			
Roofing slate	6803.00.10	6.6% ad valorem	25% ad valorem.
Other	6803.00.50	3.7% ad valorem	25% ad valorem.

TABLE 3
DIMENSION STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE¹

State	1989		1990 ^a		1991	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Alabama	W	W	W	W	9,552	\$2,449
Arkansas	W	W	W	W	13,932	1,128
California	28,829	\$5,564	30,077	\$5,216	44,757	5,254
Colorado	5,310	398	8,490	1,394	W	W
Connecticut	W	W	W	W	17,326	1,739
Georgia	² 153,440	² 12,564	147,068	12,483	² 173,892	² 14,167
Idaho	W	W	W	W	3,596	W
Indiana	² 198,531	² 27,213	194,728	29,504	² 187,580	² 27,491
Iowa	15,151	613	W	W	W	W
Kansas	W	W	W	W	19,651	2,171
Maine	W	W	W	W	73	88
Maryland	27,529	2,072	24,102	1,751	12,090	967
Massachusetts	67,533	10,302	56,254	10,992	69,332	11,646
Minnesota	44,605	16,031	60,195	20,836	45,795	13,962
New Hampshire	55,305	8,769	45,073	6,029	34,803	5,013
New York	23,756	3,575	23,437	3,589	18,624	2,978
North Carolina	62,665	10,477	66,531	11,551	32,489	10,128
Ohio	59,923	3,455	61,783	3,468	² 42,355	² 2,279
Oklahoma	8,663	1,418	8,138	684	³ 3,836	² 596
Pennsylvania	44,267	10,032	43,952	9,898	38,493	10,077
South Carolina	W	W	W	W	8,829	854
South Dakota	56,963	17,765	50,688	12,871	W	W
Tennessee	4,888	437	10,108	2,051	3,460	260
Texas	81,268	12,449	84,500	12,600	W	W
Vermont	100,677	31,413	99,243	28,950	92,676	31,013
Virginia	W	W	W	W	11,046	3,061
Wisconsin	43,526	4,794	31,316	3,811	³ 37,470	² 4,347
Other ³	155,000	31,629	140,533	32,016	217,476	45,473
Total ⁴	1,237,829	210,968	1,186,216	209,691	1,139,133	197,142

^aEstimated. W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Includes Puerto Rico.

²Totals only include Georgia granite, Indiana limestone, Ohio sandstone, Oklahoma granite, Wisconsin limestone and granite; other stone included with "Other."

³Includes data for Arizona, Illinois, Michigan, Missouri, Montana, New Mexico, Puerto Rico, and Washington, and data that are withheld.

⁴Data may not add to totals shown because of independent rounding.

TABLE 4
DIMENSION GRANITE SOLD OR USED BY PRODUCERS IN THE
UNITED STATES, BY STATE

State	1990*		1991		
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
Georgia	147,068	\$12,483	173,892	1,746	\$14,167
Maine	W	W	73	1	88
Massachusetts	64,532	10,147	69,232	840	11,576
New Hampshire	52,995	8,717	34,803	422	5,013
Oklahoma	5,261	1,348	3,836	45	596
Pennsylvania	11,157	3,092	12,354	147	3,275
South Carolina	W	W	8,829	107	854
South Dakota	54,580	17,656	W	W	W
Vermont	79,620	15,424	72,537	895	W
Wisconsin	W	W	4,278	47	2,661
Other ¹	218,701	47,365	205,468	2,344	59,533
Total²	633,914	116,232	585,302	6,595	97,761

*Estimated. W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Includes California, Colorado, Connecticut, Maryland (1990), Minnesota, Missouri, New York, North Carolina, Rhode Island, Texas, Virginia, Washington (1990), and data that are withheld.

²Data may not add to totals shown because of independent rounding.

TABLE 5
DIMENSION LIMESTONE SOLD OR USED BY PRODUCERS IN THE
UNITED STATES IN 1991, BY STATE

State	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
Indiana	187,580	2,558	\$27,491
Kansas	19,451	241	2,154
Wisconsin	33,192	415	1,685
Other ¹	76,759	931	14,074
Total²	316,982	4,144	45,405

¹Includes Alabama, Arkansas, California, Iowa, Minnesota, New Mexico, New York, Ohio, and Texas.

²Data may not add to total shown because of independent rounding.

TABLE 6
DIMENSION MARBLE SOLD OR USED BY PRODUCERS IN THE
UNITED STATES IN 1991, BY STATE

State	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
Idaho	996	12	W
Massachusetts	100	1	\$70
Other ¹	41,881	326	26,061
Total	42,977	340	26,131

W Withheld to avoid disclosing company proprietary data, included with "Other."

¹Includes Alabama, Arkansas, Colorado, Georgia, Montana, New Mexico, Puerto Rico, Tennessee, and Vermont.

²Data do not add to total shown because of independent rounding.

TABLE 7
DIMENSION SANDSTONE SOLD OR USED BY PRODUCERS IN THE
UNITED STATES IN 1991, BY STATE

State	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
New York	12,545	161	\$1,065
Ohio	42,355	584	2,279
Pennsylvania	11,052	142	1,218
Other ¹	58,105	742	2,733
Total	124,057	1,629	27,297

¹Includes Alabama, Arizona, Arkansas, California, Colorado, Indiana, Maryland, Michigan, Missouri, North Carolina, Oklahoma, Tennessee, and Virginia.

²Data do not add to total shown because of independent rounding.

TABLE 8
DIMENSION STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES¹ IN 1991, BY USE

Use	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
Rough stone:			
Rough blocks for building and construction	301,485	3,600	\$25,732
Irregular-shaped stone ²	84,101	960	4,489
Monumental	234,196	2,563	30,417
Other ³	15,339	201	2,185
Dressed stone:			
Ashlars and partially squared pieces	201,331	2,459	40,622
Slabs and blocks for building and construction	64,163	787	26,766
Monumental	39,901	434	26,880
Curbing	91,271	1,113	17,872
Flagging	23,667	301	1,473
Flagging (slate)	6,646	—	754
Roofing (slate)	12,093	—	9,271
Structural and sanitary purposed (slate)	3,307	—	2,577
Flooring (slate)	6,155	—	2,804
Other ⁴	55,478	653	5,301
Total	1,139,133	13,071	⁵197,142

¹Includes Puerto Rico.

²Includes rubble.

³Includes rough stone used for flagging (1990) and unspecified uses.

⁴Includes a minor amount of slate used for billiard tabletops, blackboards, bulletin boards, and school slates and unspecified uses.

⁵Data may not add to totals shown because of independent rounding.

TABLE 9
DIMENSION GRANITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1991, BY USE

Use	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
Rough stone:			
Rough blocks for building and construction	128,247	1,448	\$11,718
Irregular-shaped stone ¹	7,793	85	600
Monumental	230,344	2,520	30,030
Dressed stone:			
Ashlars and partially squared pieces	78,717	904	16,796
Slabs and blocks for building and construction	21,730	259	4,479
Monumental	30,841	328	17,159
Curbing	80,524	974	16,517
Other ²	7,106	78	462
Total	585,302	³6,595	97,761

¹Includes rubble and a minor amount of unspecified uses.

²Includes unspecified uses for dressed stone.

Data do not add to total shown because of independent rounding.

TABLE 10
DIMENSION LIMESTONE SOLD OR USED BY PRODUCERS IN THE
UNITED STATES IN 1991, IN BY USE

Use	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
Rough stone:			
Rough blocks for building and construction	131,554	1,771	\$11,322
Other ¹	49,418	633	4,076
Dressed stone:			
Ashlars and partially squared pieces	79,120	996	19,470
Slabs and blocks for building and construction	26,712	348	8,766
Flagging	7,760	95	677
Other ²	22,418	302	1,094
Total	316,982	³4,144	45,405

¹Includes rubble, irregular-shaped stone, monumental, and rough sawed stone.

²Includes dressed monumental stone and unspecified uses.

³Data do not add to total shown because of independent rounding.

TABLE 11
DIMENSION MARBLE SOLD OR USED BY PRODUCERS IN THE
UNITED STATES¹ IN 1991, BY USE

Use	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
Rough stone:			
Rough blocks for building and construction	17,375	52	\$1,820
Other ²	2,343	24	248
Dressed stone:			
Ashlars and partially squared pieces	2,433	29	W
Slabs and blocks for building and construction	11,695	128	13,160
Other ³	9,131	107	10,903
Total	42,977	340	26,131

W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Includes Puerto Rico.

²Includes rubble, irregular-shaped stone, monumental stone, and unspecified uses.

³Includes stone used for monumental purposes, a small amount used in flagging, and unspecified uses.

TABLE 12
DIMENSION SANDSTONE SOLD OR USED BY PRODUCERS IN THE
UNITED STATES IN 1991, BY USE

Use	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
Rough stone:			
Rough blocks for building and construction	20,913	287	\$623
Irregular-shaped stone ¹	27,625	356	881
Other ²	3,460	43	286
Dressed stone:			
Ashlars and partially squared pieces	26,189	350	1,823
Slabs and blocks for building and construction	4,026	52	361
Flagging	10,217	135	377
Other ³	31,627	407	2,947
Total⁴	124,057	1,629	7,297

¹Includes rubble.

²Includes monumental stone and uses not specified.

³Includes dressed monumental stone, curbing, and unspecified uses.

⁴Data may not add to totals shown because of independent rounding.

TABLE 13
DIMENSION SLATE SOLD OR
USED BY PRODUCERS IN THE
UNITED STATES IN 1991, BY USE

Use	Quantity (short tons)	Value (thousands)
Flagging	6,646	\$754
Roofing	12,093	9,271
Structural and sanitary purposes	3,307	2,577
Flooring	6,155	2,804
Other ¹	4,573	2,109
Total	32,774	²17,516

¹Includes a minor amount of slate used for billiard tabletops, lockboards, school slates, and unspecified uses.

Data do not add to total shown because of independent rounding.

TABLE 14
U.S. EXPORTS OF DIMENSION STONE, BY TYPE

(Thousand short tons and thousand dollars)

	1990		1991		Major destination in 1991, percent ¹
	Quantity	Value	Quantity	Value	
Marble, travertine, alabaster worked	34	4,905	25	2,560	Canada, 45.
Marble, travertine—crude or roughly trimmed	25	671	9	2,548	Italy, 75.
Marble, travertine—merely cut, by sawing or otherwise	3	1,650	9	6,380	Japan, 68.
Granite, crude or roughly trimmed	75	10,195	62	11,414	Japan, 38.
Granite, merely cut by sawing or otherwise	NA	10,734	33	13,838	Japan, 39.
Granite, dressed, worked	NA	11,351	28	12,702	Canada, 70.
Sandstone, crude or roughly trimmed	7	334	1	203	Canada, 85.
Sandstone, merely cut, by sawing or otherwise	12	2,280	8	1,453	Canada, 93.
Slate, worked and articles of slate	NA	8,732	NA	8,412	Cayman, 23.
Slate, whether or not roughly trimmed or merely cut	NA	636	NA	646	Canada, 71.
Other calcareous monumental or building stone; alabaster	5	698	27	2,767	Canada, 67.
Other monumental or building stone	13	1,833	10	2,024	Canada, 51.
Total	NA	54,019	NA	64,947	

¹Revised. NA Not available.

¹By value.

Source: Bureau of the Census.

TABLE 15
U.S IMPORTS FOR CONSUMPTION OF DIMENSION GRANITE, BY COUNTRY
(Thousand cubic feet and thousand dollars)

Country	Rough granite ¹		Stone and articles		Dressed granite ²		Total	
	Quantity	Value	Quantity	Value	Worked		Quantity	Value
					Quantity	Value		
1988:								
Canada	654	5,790	—	—	—	—	245	16,600
Italy	23	253	—	—	—	—	4,220	109,000
Portugal	246	881	—	—	—	—	80	940
South Africa, Republic of	91	2,495	—	—	—	—	505	14,700
Spain	26	60	—	—	—	—	1,340	23,760
Other	60	821	—	—	—	—	6,390	165,000
Total	1,100	10,300						
1989:								
Argentina	71	778	22	555	68	1,710	90	2,265
Brazil	388	882	6	494	270	3,350	276	3,844
Canada	900	8,093	18	4,432	250	14,841	268	19,273
China	106	365	17	345	30	654	47	999
India	99	3,169	98	980	380	5,633	478	6,613
Italy	984	14,607	760	18,237	2,860	84,221	3,620	102,458
Japan	21	206	(^c)	3	4	122	4	125
Mexico	6	63	—	—	110	2,248	110	2,248
Portugal	314	990	3	64	28	326	31	390
Saudi Arabia	3	27	10	336	11	346	21	682
South Africa, Republic of	82	2,477	—	—	—	—	—	—
Spain	474	1,281	40	3,995	449	11,091	489	15,086
Other	165	1,969	73	1,906	103	3,477	176	5,383
Total	3,613	34,907	1,047	31,347	4,563	128,019	5,610	159,366
1990:								
Argentina	20	244	34	650	81	2,149	115	2,799
Brazil	186	466	57	716	258	4,016	315	4,732
Canada	650	6,506	30	2,068	278	21,350	308	23,418
China	120	450	10	195	75	1,599	85	1,794
Finland	6	94	—	—	5	1,405	5	1,405
India	45	1,578	246	674	492	9,736	738	10,410
Italy	343	5,138	726	17,040	3,095	91,096	3,821	108,136
Japan	5	55	(^c)	51	7	215	7	266
Mexico	3	35	1	22	45	1,002	46	1,024
Norway	11	499	9	51	10	94	19	145
Portugal	225	709	54	390	72	1,235	126	1,625
Saudi Arabia	—	—	18	463	12	404	30	867
South Africa, Republic of	86	2,790	1	53	13	556	14	609
Spain	66	189	50	1,283	450	14,135	500	15,418
Other	44	469	24	616	82	2,707	106	3,323
Total	1,810	19,222	1,260	24,272	4,975	151,699	6,235	175,971
1991:								
Argentina	11	135	13	243	80	2,135	93	2,378
Brazil	151	377	125	1,576	347	5,395	472	6,971
Canada	450	5,128	35	2,423	217	16,664	252	19,087
China	77	290	20	394	101	2,163	121	2,557

See footnotes at end of table.

TABLE 15-Continued
U.S IMPORTS FOR CONSUMPTION OF DIMENSION GRANITE, BY COUNTRY
 (Thousand cubic feet and thousand dollars)

Country	Rough granite* 1		Stone and articles		Dressed granite*		Total	
	Quantity	Value	Quantity	Value	Worked		Quantity	Value
					Quantity	Value		
1991—Continued:								
Finland								
India	5	94	(²)	3	(²)	79	(²)	82
Italy	9	304	285	781	559	11,065	844	11,846
Japan	166	2,485	436	10,232	2,468	72,535	2,904	82,767
Mexico	2	20	1	82	10	297	11	379
Norway	6	66	(²)	2	8	56	8	58
Portugal	3	159	9	57	20	185	29	242
Saudi Arabia	450	1,418	22	160	60	1,038	82	1,198
South Africa, Republic of	11	102	1	35	15	509	16	544
Spain	40	1,287	—	—	8	406	8	406
Other	10	29	29	748	312	9,790	341	10,538
Total	36	384	9	241	100	3,338	109	3,579
	1,427	12,278	985	16,977	4,305	125,655	5,290	142,632

*Estimated.

¹Includes crude or roughly trimmed, and merely cut by sawing or otherwise.

²Less than 1/2 unit.

Source: Bureau of the Census for values and the U.S. Bureau of Mines for quantity.

TABLE 16
U.S IMPORTS FOR CONSUMPTION OF MAJOR CATEGORIES OF OF DIMENSION MARBLE AND OTHER
CALCAREOUS STONE, BY COUNTRY

(Short tons)

Country	Dressed marble slabs		Dressed marble—other		Dressed marble and other calcareous stone ¹		Rough marble ²	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
1989	217,382	\$187,000	65,418	\$58,189	22,660	\$10,465	29,994	\$15,000
1990:								
China	3,968	3,181	778	719	1,246	1,036	168	132
France	834	1,357	322	480	39,663	17,651	109	171
Greece	15,711	17,604	3,116	2,916	7,335	2,756	2,946	555
Italy	78,104	88,564	42,544	47,920	38,845	28,070	4,071	3,025
Portugal	5,028	5,001	1,297	1,616	4,346	2,880	47	43
Spain	15,482	14,164	5,897	6,587	18,923	14,245	239	235
Other	18,419	17,211	17,273	19,931	15,886	8,604	1,948	1,836
Total	137,546	147,082	71,227	80,169	126,244	75,242	9,528	5,997
1991:								
China	3,881	2,772	2,090	1,525	2,143	1,449	144	132
France	378	851	548	450	13,483	11,560	53	81
Greece	6,463	7,917	3,581	3,567	4,661	3,378	216	149
India	525	531	197	115	121	112	153	315
Italy	37,808	42,615	34,346	37,909	45,029	36,842	2,099	2,701
Mexico	753	753	2,289	2,218	14,681	7,940	109	107
Portugal	2,367	2,349	893	987	6,220	3,662	32	26
Spain	5,109	5,441	5,618	6,287	18,226	15,445	—	—
Other	11,274	10,398	13,963	18,115	44,516	6,347	779	584
Total	68,558	73,627	63,525	71,173	149,080	86,735	3,585	4,095

¹HTS No. 6802.92: The material from Italy is almost all marble; from France, is both limestone and marble; from Spain, is almost all marble; and from Mexico, is both limestone and marble.

²Marble—merely cut by sawing or otherwise.

Source: Bureau of the Census as Modified by the U.S. Bureau of Mines.

TABLE 17
U.S. IMPORTS FOR CONSUMPTION OF DIMENSION STONE, BY TYPE

Type		1990		1991		Major source for 1991, percent ¹
		Quantity	Value (thousands)	Quantity	Value (thousands)	
Calcareous stone—other ²	short tons	15,807	2,188	35,026	2,433	Mexico, 43.
Marble, travertine alabaster and other	do.	8,591	7,976	6,324	6,985	Italy, 63.
Sandstone, merely cut, by sawing or otherwise	do.	475	168	250	211	Canada, 24.
Slate, roofing	million square feet	9.8	4,909	5.0	2,948	Spain, 49.
Slate, whether or not roughly trimmed or merely cut		NA	1,816	NA	1,845	Italy, 77.
Slate, worked and articles of slate, and other		NA	14,346	NA	15,889	Italy, 56.
Stone, worked monumental or building stone—other	short tons	28,119	33,098	36,073	41,662	Italy, 32.
Travertine, monumental or building stone and articles thereof	do.	5,109	3,015	3,243	2,117	Italy, 94.
Travertine, worked monumental or building stone	do.	34,014	11,930	12,035	7,308	Italy, 97.
Other monumental or building stone	do.	11,973	1,599	6,935	2,173	South Africa, Republic of, 4.
Other stone—monumental or building stone—articles thereof	do.	2,876	1,515	1,310	945	Mexico, 33.

NA Not available.

¹By value

²HTS No. 6802.22

Source: Bureau of the Census.

STRONTIUM

By Joyce A. Ober

Mrs. Ober, a physical scientist with 14 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for strontium since 1986. Domestic survey data were prepared by Linder Roberts, statistical assistant; and the international production table was prepared by Virginia A. Woodson, international data coordinator.

The largest consumption of strontium compounds domestically and internationally was in the production of color television picture tube faceplate glass. Strontium carbonate, produced by processing the mineral celestite, was the most important strontium compound produced. Chemical Products Corp. (CPC) of Cartersville, GA, was the only U.S. producer of strontium compounds from celestite. CPC produced compounds from imported material because there were no active celestite mines in the United States.

Strontium occurs commonly in nature, averaging 0.034% of all igneous rock; however, only two minerals, celestite and strontianite, contain strontium in sufficient quantities to make its recovery practical. Of the two, only celestite has been found to occur in deposits of sufficient size to make development of mining facilities currently attractive. Celestite, the most common strontium mineral, consists primarily of strontium sulfate. Strontianite, the second most common mineral, consists primarily of strontium carbonate. Strontianite would be the more useful of the two common minerals because strontium is used most commonly in the carbonate form, but few deposits have been discovered that are suitable for development.

DOMESTIC DATA COVERAGE

The sole U.S. strontium carbonate producer voluntarily provided domestic production data to the U.S. Bureau of Mines. Production and stock data, however, were withheld from publication

to avoid disclosing company proprietary data.

The Bureau also estimated the distribution of strontium compounds by end use. Of the 10 operations to which a survey request was sent, 8 responded. The information collected from this survey represents almost 100% of the end-use data shown in table 2. Consumption for the nonrespondents was estimated using reported prior-year consumption levels. (See table 1.)

ANNUAL REVIEW

Production

Although there have been no active celestite mines in the United States since 1959, celestite deposits have been identified nationwide. During World War II, domestic mining of celestite resources was conducted in Texas and California. U.S. celestite mines had at that time been inactive since World War I, and strontium minerals were imported to satisfy domestic demand.

Strontium carbonate, the most important strontium compound by far, was produced in 1991 by one company in the United States. CPC was the only company that produced strontium chemicals from celestite. The majority of the celestite CPC used was imported from Mexico. CPC utilizes the black ash method of strontium carbonate production at its facility. The black ash method and the soda ash method are the two most common recovery techniques. The black ash method, known alternatively as the calcining method, produces chemical-grade strontium carbonate, which contains

at least 98% strontium carbonate. The soda ash or direct conversion method produces technical-grade strontium carbonate, containing at least 97% strontium carbonate.

The black ash method received its name because the first step in the procedure involves mixing the crushed and screened celestite with powdered coal, making a black mixture. The mixture is then heated to about 1,100° C, expelling oxygen in the form of carbon dioxide from the insoluble strontium sulfate to form water-soluble strontium sulfide.

Strontium sulfide is dissolved in water and the resulting solution filtered. Carbon dioxide then passes through the solution or soda ash is added. Either compound provides the necessary carbon and oxygen for strontium carbonate to form and precipitate from the solution. The precipitated strontium carbonate is then removed from the solution by filtering and is dried, ground, and packaged. The sulfur released in the process is either recovered as elemental sulfur or in other byproduct sulfur compounds.

In the soda ash method, ground celestite is washed and most of the water removed. The thickened mixture is then mixed with soda ash and treated with steam for 1 to 3 hours. During this time, celestite and soda ash react to form strontium carbonate and sodium sulfate. Sodium sulfate is water soluble, making it possible to separate the insoluble strontium carbonate by centrifuging. Although the soda ash method is a simpler process, the lower grade of the product causes it to be the less preferred

method of recovery. The black ash method is the most common method of strontium carbonate production, and new production facilities usually use black ash technology.

CPC purchased the strontium nitrate production facilities from FMC Corp. in Modesto, CA, when that company discontinued production of carbonate and nitrate in 1984. The company moved the equipment to Cartersville and now is also the sole U.S. producer of strontium nitrate.

There are several U.S. companies that produced strontium compounds from strontium carbonate. Mallinkrodt Inc. of St. Louis, MO, produced strontium chloride, and Mineral Pigments Corp. of Beltsville, MD, produced strontium chromate. A few other companies produced downstream strontium compounds, but on a very small scale.

Domestic strontium deposits were operated in 1944 near Blanket, in Brown County, TX; in Nolan County, TX; in the Fish Mountains in Imperial County, CA; and near Ludlow, CA. At that time, the major use for strontium chemicals was for pyrotechnic applications such as signal flares and tracer bullets required for military applications. Immediately following World War II, this demand decreased markedly, causing domestic production of celestite to decrease quickly and eventually disappear.

Resources in the United States have been estimated at 3.2 million metric tons, with an identified reserve base of 1.4 million tons. The reserve figure includes material containing no more than 60% strontium sulfate, which is much too low grade to meet today's rigid specifications. In addition to deposits operated in the early 1940's, celestite has been discovered in Arizona, Arkansas, Kentucky, Michigan, Missouri, New York, Ohio, Pennsylvania, Tennessee, Utah, and Washington.

Consumption and Uses

Approximately 80% of all strontium was consumed in ceramics and glass manufacture, primarily in television faceplate glass and ceramic ferrite

magnets, and in smaller amounts in other ceramic and glass applications. Over the past 20 years, color television production has become the major consumer of strontium. Because of unique properties that strontium compounds possess, technologies have developed that take advantage of those properties for specific applications. All color televisions and other devices containing color cathode-ray tubes sold in the United States were required by law to contain strontium in the faceplate glass of the picture tube. Strontium blocks X-rays better than barium, which was previously used, and although lead is a better X-ray barrier than strontium, it causes a browning of the glass, which makes its use undesirable. Major manufacturers of television picture tube glass incorporate about 8%, by weight, strontium oxide in their glass faceplate material. The strontium is added to the glass melt in the form of strontium carbonate, and during processing, it is converted to strontium oxide. In addition to blocking X-rays, the strontium improves the appearance of the glass, increasing the brilliance and improving the quality of the picture.

Trends in television production show a shift to larger, flatter tubes that require thicker glass, and therefore, more strontium. Although the television industry in the United States is considered mature, there is a continuing demand for replacement televisions as well as additional sets in large numbers of households. The trend to personal computers and sophisticated, computerized instrumentation increased the demand for strontium in color monitors for these devices.

Permanent ceramic magnets were another large end use for strontium compounds, in the form of strontium ferrite. When these magnets were first developed, they were used primarily as magnetic closures for refrigerator doors. Applications have expanded to include extensive use in small direct current (dc) motors, especially for automotive applications such as windshield-wiper motors, as well as loudspeakers, other electronic equipment, toys, and magnetically attached decorative items.

Strontium ferrites are used in permanent ceramic magnets because they have high coercive force, high thermal and electrical resistivity, and are chemically inert. They retain their magnetism well, are not adversely affected by electrical currents or high temperatures, and do not react with most chemical solvents. Other properties that make the strontium magnets more attractive for specific applications are their resistance to demagnetization and lower density, making them more desirable in applications where weight is a factor.

Barium or lead can replace the strontium in ferrite magnets, but strontium ferrites have been found to possess the best combination of properties necessary for superior magnets.

One of the most consistent and continuing applications for strontium has been in pyrotechnic devices. Strontium burns with a brilliant red flame, and no other material has been found to be better in this application.

The strontium compound used most frequently in pyrotechnic devices was strontium nitrate. Some strontium compounds are slightly hygroscopic, but strontium nitrate takes on very little water and imparts the desired brilliant red. Strontium carbonate, strontium oxalate, strontium sulfate, and strontium chlorate can be used in pyrotechnic applications, but strontium nitrate was used in significantly larger quantities than any of these.

Pyrotechnic devices were used in military and nonmilitary applications. Military pyrotechnic applications that contained strontium included tracer ammunition, military flares, and marine distress signals. Nonmilitary applications included warning devices and fireworks.

Zinc used in diecasting alloys is required to contain less than 0.003% lead. Strontium was used to remove lead impurities during the electrolytic production of zinc. Addition of strontium carbonate in sulfuric acid to the electrolyte reduced the lead content of the electrolyte and of the zinc that is deposited on the cathode.

The addition of strontium chromate to paint creates a coating that is resistant to corrosion. It is an effective coating for aluminum, most notably on aircraft fuselages and ships. These paints are used to some degree on aluminum packaging to prevent package corrosion. The nitrate and chloride contents of strontium chromate paint pigment are very strictly controlled to prevent corrosion.

Consumption of metallic strontium was still a very limited factor in total strontium consumption. Small amounts of strontium are added to molten aluminum to improve the castability of the metal, making it much more suitable for casting items that have been traditionally made from steel. The addition of strontium to the melt improves the machinability of the casting. The use of cast aluminum parts is currently gaining popularity in the automotive industry. Aluminum parts were impractical before modification techniques were developed. The reduction in the weight of the automobile by using cast aluminum parts instead of steel helps to improve energy efficiency of the cars incorporating these parts.

At the present time other end uses consume only small amounts of strontium and strontium compounds. As mentioned previously, the presence of strontium in glass applications improves the brilliance of the glass. It also improves the quality of certain ceramic glazes as well as eliminating the toxicity that may be present in glazes containing lead or barium. One high-tech strontium ceramic is strontium titanate, which is sometimes used as substrate material for semiconductors and also in some optical and piezoelectric applications.

Strontium chloride was used in toothpaste for sensitive teeth. For this application, impurities must be strictly controlled, with limits for some of them in the parts per million range.

Strontium phosphate was used in the manufacture of fluorescent lights, and the entire range of strontium chemicals was used in analytical chemistry laboratories. (See table 2.)

Prices

The average customs value for celestite imported from Mexico was about \$78 per ton (\$70 per short ton), slightly less than the average value in 1990. Mexico was the source of almost 100% of celestite imports in 1991. Values of imported strontium compounds varied according to the type of compound and the country of origin.

Foreign Trade

According to reports from the Bureau of the Census, exports of strontium compounds decreased 37% from the levels reported in 1990. Imports of celestite decreased 32% from the levels reported in 1990.

Mexico continued as the most important source for imported strontium compounds; the Federal Republic of Germany was second. Imports of strontium carbonate in 1991 were 19% lower than those in 1990, with imports from Mexico being the largest percentage of total imports but less than those in 1990. Strontium carbonate imports from Germany increased. Imports of strontium nitrate were slightly higher than those in 1990. (See tables 3, 4, and 5.)

World Review

In almost all instances, celestite deposits occur in remote, undeveloped locations far from population centers in areas where inexpensive labor is available for mining. Huge deposits of high-grade celestite have been discovered throughout the world. Strontium commonly occurs along with barium and calcium, two elements with chemical properties very similar to strontium, thus making separation difficult. Because removing many impurities from celestite is difficult and energy intensive, current strontium chemical producers require material to contain at least 90% strontium sulfate. Most of the currently operating celestite facilities can produce sufficient supplies with only minimal processing necessary to achieve acceptable specifications. Hand sorting and some washing are all

that are necessary at many strontium mines; only a few operations use froth flotation or gravity separation to beneficiate their ore.

Detailed information on most world resources is not readily available. Many of the large deposits are in remote, sparsely inhabited areas, and very little formal exploration has been done. Other deposits may be well identified but are in countries from which specific mineral information is not easily obtained.

Capacity.—The data in table 6 are annual rated capacity for chemical processing plants as of December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

Two types of strontium capacity exist, ore production capacity and compound production capacity. Strontium compound capacity was deemed the more important for several reasons. Essentially all strontium is consumed in compound form, primarily as the carbonate and to a lesser extent as the nitrate. Strontium carbonate is also the intermediate product in production of downstream compounds. At least 12 countries mined celestite in 1991. Virtually all of the celestite mined annually is consumed in the production of strontium carbonate and other strontium compounds. Very little strontium was consumed directly in the mineral form.

Listing both ore and compound production capacity could be misleading, possibly resulting in double-counting of strontium capacity. Because most ore is produced for market by means of very simple sorting and beneficiation techniques, capacity can easily be raised to meet increased demand. Strontium carbonate production capacity is the limiting factor in strontium production,

requiring complicated and sophisticated processing facilities. Therefore, strontium carbonate production capacity, reported in terms of contained strontium, was selected for tabulation. Construction to expand strontium carbonate capacity has increased because of the continued growth in international sales of color television sets. Capacity information was compiled from published reports. (See table 6.)

Algeria.—Celestite was mined in Algeria from a surface deposit near Beni Mansour. Estimated reserves were more than 1 million metric tons. The deposit was mined by Enterprise des Produits Non-ferreux et des Substances Utiles (ENOF) and was controlled by L'Enterprise Nationale de Developpement Minière (Edemines), a division of Société Nationale de Recherches et d'Exploitations Minières (SONAREM). No strontium has been exported in recent years, but in the past, up to 3,600 tons per year has been exported to nations in Eastern Europe and the Federal Republic of Germany. Although the celestite was relatively low grade, only about 70% strontium sulfate, it contained low concentrations of barite, silica, gypsum, and iron, making it possible to concentrate the ore to acceptable levels using only gravity separation. The deposit has not been fully exploited, but there is interest in further development.¹

Argentina.—Celestite mining was controlled by the Argentine Mining Union at the San Juan Mine in the Province of Mendoza. Celestite has been identified at several other small mines, the Maria Del Carmen and Don Luis Mines also in Mendoza Province and the Rayoso, Julio, Cerro Partido, and Llao Llao Mines in the Province of Neuquen. It is unlikely that any production was carried out on a regular basis at these mines. Most Argentine production was exported to Brazil.²

Canada.—Canada has produced celestite ore in the past from the McRae deposit, also known as the old Kaiser

Celestite Mining Ltd. mine. It is at Enon, Cape Breton County, Nova Scotia. Mineral rights were acquired by Timminco Metals, a division of Timminco Ltd. of Toronto in 1985. Exploration identified reserves of more than 1 million tons of celestite, with grades ranging from 60% to 65% strontium sulfate. Reopening the mine has been considered, but the low grade of the ore makes economic feasibility questionable. Other strontium deposits have been identified in British Columbia, Newfoundland, and Ontario,³ but none as significant as the deposit in Nova Scotia. Timminco Metals was the largest producer of strontium metal in the world and the only producer of strontium metal in North America. The company operated a processing facility in Westmeath, Ontario. The strontium production facilities in Westmeath and facilities in Haley, Ontario, produce strontium metal by the aluminothermic reduction of strontium oxide.

China.—Celestite was mined in China almost exclusively for domestic consumption. An ore-dressing facility at the Nanjing Mine in Jiang Su Province has a capacity of 10,000 tons per year. The Nanjing deposit is reported to be high grade and close enough to the surface for open pit mining.⁴ Past import data indicated that strontium chemical plants must exist, but no specific details were available. Reports indicated that Japan imports strontium carbonate from China and that strontium carbonate from China has also been reported in the United States.

Cyprus.—Celestite mining began in Cyprus in 1985 at Vassliko, near Limassol, in southern Cyprus. The mine was operated by Hellenic Mining Co. Ltd. The ore averaged about 54% strontium sulfate and, therefore, required concentration to make it marketable. The ore was beneficiated through a flotation process to reach 94% strontium sulfate. The reserves have been determined to be 200,000 tons of celestite.⁵ No mining has occurred for the past 4 years.

Germany, Federal Republic of.—Kali-Chemie AG of Hannover produced strontium carbonate from imported celestite at its plant at Bad Hoenningen. The major western European producer used the black ash method in the production facilities. Plant capacity is estimated to be 15,000 tons per year. Kali-Chemie imported most of its celestite from Spain and Turkey; it exported 80% to 90% of the production, most of which goes to the United States and the Republic of Korea. Kali-Chemie also produced strontium hydroxide and strontium nitrate. The nitrate was produced by its Italian subsidiary, Societa Bario e Derivati SpA, in Massa.⁶

Iran.—One of the world's largest celestite deposits is in the northwestern part of the Dasht-e-Kavir salt desert. The deposit was mined by Iran Strontium Co., a subsidiary of Cherkate Sahami Sanati Va Maadani Irani (Simiran). Average strontium sulfate values for the deposit were reported at more than 91%, but there were unfavorably high levels of barium sulfate and calcium sulfate. Proven reserves total 1.8 million tons of celestite, 430,000 tons of which have no overburden.⁷ Most of the celestite produced from this deposit is believed to go to the U.S.S.R.

Italy.—Mining has been done by Minera Chimica Farnesiana SpA in Tarquinia, near Rome. Most production of this 75% strontium sulfate and 5% barium sulfate product was sold domestically. Annual production capacity at the mine was 7,300 tons per year, but production ceased in 1988. Some of the processed ore has been exported to the U.S.S.R. in the past. Other deposits are known to exist in the interior of Sicily, although none have recently been mined. Societa Bario e Derivati, a subsidiary of Kali-Chemie AG of the Federal Republic of Germany, produced strontium nitrate at Massa. Production and capacity figures were not available, but it was known that most of the production is exported to the United States.⁸

Japan.—Although celestite was not mined in Japan, it was the largest consumer of strontium carbonate in the world, mostly due to its large television and electronics industry. Four companies produce strontium carbonate from imported celestite. Honjo Chemical Corp. operated a production facility for 18,000 tons per year of carbonate at Neyagawa in Osaka using celestite from Spain and China. Sakai Chemical Industries Co. also produced strontium carbonate, by the black ash method, in Osaka at a 12,000-ton-per-year plant using Chinese, Mexican, and Spanish celestite. Japan Special Chemicals (Nihon Tokushu Kasei) and Dow Chemicals also produced strontium carbonate, but on a much smaller scale. The total capacity for both companies was only about 1,100 tons per year. These two companies used celestite from Spain.⁹

Korea, Republic of.—Although celestite deposits have not been identified in Korea, its growing electronics and television industry prompted a European company to form a joint venture with a Korean firm. Kali-Chemie and Samsung Corning Ltd., Korea, formed Daehan Specialty Chemicals Co. Ltd. to build a strontium carbonate and barium carbonate plant. The plant began operation in 1990 with a production capacity of 40,000 tons per year of strontium carbonate and barium carbonate, combined. The production was marketed to the growing television industry in that country. The black ash method was used.¹⁰

Mexico.—CPC's new strontium carbonate plant in Reinos, Tamaulipas, close to the U.S. border, began production toward the end of 1991. Capacity was reported at about 22,000 tons per year. Already possessing the capability to produce more strontium carbonate than any other country in the world, with the completion of this project, Mexico's strontium carbonate production capacity is about 42% of the known world total.

Strontium carbonate production has been a recent development in Mexico. This is a very attractive location for additional production facilities because of the huge celestite resources in the country. After a major U.S. strontium carbonate and strontium nitrate producer (FMC Corp.) closed its plant in 1984, Cia. Minera La Valenciana SA (CMV) bought the strontium carbonate processing equipment from the FMC plant in California. The plant, which utilized the soda ash method of carbonate production and was converted to the black ash method, was relocated to Torreón in Coahuila State, near a company-operated mine. The plant capacity is 50,000 tons per year. Shipments from the plant, targeted for the television and electronics industry in the Far East, commenced in May 1987. Sales y Oxidos (SYOSA), 49% owned by Kali-Chemie, built a new strontium carbonate plant near Monterrey with the capacity of 15,000 tons per year. The company's old strontium carbonate operation was converted to produce barium carbonate. SYOSA, which produced carbonate by the black ash method from celestite it mines nearby, marketed its production in the United States.¹¹

Mexico was the world's largest producer of celestite in 1991. The most recent Directory of Mexican Non-Metallic Minerals Trust lists 11 companies currently mining celestite. CMV mined celestite from the San Agustín deposit near Torreón, and Compañía Minera Ocampo SA mined a deposit near Saltillo in Nuevo Leon State, as well as some small production in Hidalgo, Aguascalientes, and Chihuahua states. Reserves of the San Agustín Mine alone have been estimated at more than 725,000 tons. SYOSA mines west of Monterrey. Other small operations occur in Coahuila, Aguascalientes, Chihuahua, and Nuevo Leon. Mexican celestite is primarily high grade, and only hand sorting is required to achieve at least 92% strontium sulfate with low barium content. Abandoned mines and easily identified deposits that have not yet been developed are common throughout a large area in northern Mexico. Reserves are believed to be

vast, but these deposits have not been extensively explored.¹²

Pakistan.—All strontium mines in Pakistan are the property of Provincial governments and are operated by private companies for the governments. Recent celestite production figures have been reported for two active mines, one near Dawood Khail and one near Karachi.¹³ Tawakkal Mineral Exports Corp. recovered celestite from these mines in the Dadu District of Sind Province. No beneficiation was necessary to produce 94% strontium sulfate. Reserves of celestite have not been quantified at this location.¹⁴ Other deposits with 500,000 tons of reported reserves have been identified in the Punjab Province.¹⁵

Spain.—Spain was another of the largest celestite producers worldwide. Celestite was produced from the Monteive deposit, which was operated by Herederos de Aurelio Farjardo Vilches, with sales and marketing handled by Bruno SA. Selective mining and hand sorting was all that was necessary to produce ore grades of more than 92% strontium sulfate, although a concentration plant has been constructed. Reserves are believed to be at least 2 million tons. Most Spanish production is exported to Japan, some remains in Spain, and the rest is exported to the Federal Republic of Germany.¹⁶ Promotora de Industria del Sur (Proinsur SA) produced strontium carbonate and strontium nitrate at a combined facility near Granada. The plant has a theoretical design capacity of 8,000 tons per year of carbonate but has never reached this capacity. Strontium carbonate was produced by the soda ash method. The plant also has a production capacity of about 3,000 tons per year of nitrate, which has not yet been fully utilized.¹⁷

Turkey.—Turkey competes with Mexico, Spain, and Iran in claiming the world's largest strontium reserves. Barit Maden Turk AS produced celestite from a mine near Sivas. Run-of-mine ore was gravity separated to produce a concentrate

with a minimum of 95% strontium sulfate. Because of the harsh climate in the region, the mine can only be operated on a seasonal basis, from May to October. Another mine near Sivas was formerly operated by Bilfer Madencilik AS, which reestablished concessions for future celestite mining. Identified reserves have been placed at 550,000 tons, and further reserve potential is estimated to be greater than 2 million tons. Turkish celestite was primarily exported to the Federal Republic of Germany.¹⁸

U.S.S.R.—Very little is known about production of strontium minerals in this area. Deposits are known in the Karakum Desert, Zaunguz Plateau; Permian deposits near Bashkir; caprocks of the Romy and Isachkov salt domes; Pinega area, Archangel Province; Yakutsk, eastern Siberia; and in Turkestan from eastern Fergana to the shores of the Caspian Sea, and from southeastern Bucharria to the shores of the Sea of Aral. Reserves are believed to be very large, but the ore grade is probably not high.¹⁹ No details are available concerning the production of strontium carbonate in the U.S.S.R. except that there is production, probably from domestic celestite as well as from imports from Iran and Turkey.

United Kingdom.—Until World War II, virtually all celestite processed in the United States was imported from the United Kingdom. When the war interfered with transportation of the ore, other sources were developed, and the United Kingdom celestite never regained its prominence. Celestite deposits, which occur in the Bristol area, were mined by Bristol Minerals Co. Ltd. The ore was crushed, washed, and graded to achieve a product with 95% strontium sulfate. The British deposits continue to be encroached upon by large-scale housing developments, limiting possible exploitation of the minerals to the near future. This was one of the few sites where celestite deposits are not in remote locations.²⁰

These reserves nearly have been exhausted, and the mining of celestite at this site will be phased out over the next 2 years. Bristol began reprocessing mine tailings and was no longer mining primary ore.²¹ (See table 7.)

OUTLOOK

The future continues to look bright for the strontium industry for the near term. Continued growth is expected in the color television industry, and larger screens are expected to increase in popularity. Demand for strontium carbonate for television application should expand. Other markets will probably continue at their current, slower rate. Development of a technology to produce an affordable flat television display could severely reduce the demand for strontium carbonate, but this is not expected in the near future. Although a high-quality, large, flat screen is not yet available, small models are, and research continued to improve the technology. The question remains whether a new display system can be developed that will be economically attractive to the general public. Initial devices are expected to find application in military hardware and other sophisticated medical and scientific instrumentation. Flat screen display systems may eventually replace cathode-ray tubes, and, at that point, strontium producers may experience a serious setback.

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TABLE 1
SALIENT STRONTIUM STATISTICS

(Metric tons of contained strontium unless otherwise noted¹)

	1987	1988	1989	1990	1991
United States:					
Production, strontium minerals	—	—	—	—	—
Imports for consumption:					
Strontium minerals	16,900	18,100	12,000	21,500	14,600
Strontium compounds	5,000	7,800	11,300	11,800	9,500
Exports (compounds)	² 1,600	² 3,000	² 3,200	² 700	1,080
Shipments from Government stockpile excesses	—	—	—	—	—
Price, average value of mineral imports at port of exportation, dollars per ton	³ 95	³ 85	³ 76	³ 86	³ 77
World production ³ (celestite)	¹ 182,667	¹ 224,133	¹ 251,941	¹ 236,000	¹ 240,000

¹Estimated. ²Revised.

³The strontium content of celestite is 43.88%, which was used to convert units to celestite.

²Export data are obtained from the Journal of Commerce Port Import/Export Reporting Service.

³Excludes China and the U.S.S.R.

TABLE 2
U.S. ESTIMATED DISTRIBUTION OF PRIMARY STRONTIUM COMPOUNDS, BY END USE

(Percent)

End use	1988	1989	1990	1991
Electrolytic production of zinc	4	4	3	2
Ferrite ceramic magnets	11	10	9	7
Pigments and fillers	4	3	4	6
Pyrotechnics and signals	10	10	11	13
Television picture tubes	68	70	70	70
Other	3	3	3	2
Total	100	100	100	100

TABLE 3
U.S. EXPORTS FOR CONSUMPTION OF STRONTIUM COMPOUNDS,
BY COUNTRY

	1990		1991	
	Kilograms	Value ¹	Kilograms	Value ¹
Strontium carbonate— precipitated:				
Argentina	331,911	\$51,625	—	—
Canada	318,349	278,633	57,113	\$73,140
France	18,000	14,919	—	—
Mexico	2,396	6,567	44,544	27,209
Peru	—	—	18,000	12,600
Taiwan	2,120,939	1,700,819	1,628,891	1,304,028
United Kingdom	9,070	53,550	4,702	29,880
Total	2,800,665	2,106,113	1,753,250	1,446,857
Strontium oxide, hydroxide, and peroxide:				
Canada	19,362	12,180	2,874	3,277
Chile	18,617	33,939	—	—
China	544	9,020	—	—
Germany, Federal Republic of	4,801	7,386	—	—
Israel	244	5,040	27,890	71,400
Italy	—	—	108	4,407
Japan	—	—	1,153	18,731
Korea, Republic of	12,271	48,290	2,963	19,230
Mexico	—	—	1,649	6,630
Norway	742	10,818	368	6,884
Spain	13,608	20,269	—	—
Taiwan	1,300	17,511	5,342	158,515
United Kingdom	9,951	27,270	—	—
Venezuela	—	—	4,624	29,362
Total	81,440	191,723	46,971	318,436

¹Customs value.

Source: Bureau of the Census.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF STRONTIUM MINERALS,¹
BY COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value ² (thousands)	Quantity (metric tons)	Value ² (thousands)
Mexico	46,484	\$3,727	33,203	\$2,558
Spain	2,234	425	—	—
Other	6	37	1	19
Total	48,724	4,189	33,204	2,577

¹Celestite (strontium sulfate).

²Customs value.

Source: Bureau of the Census.

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF STRONTIUM COMPOUNDS,
BY COUNTRY

	1990		1991	
	Kilograms	Value ¹	Kilograms	Value ¹
Strontium carbonate:				
Canada	17,781	\$2,978	—	—
China	75,000	45,558	87,000	\$51,674
Germany, Federal Republic of	2,806,028	2,018,791	2,953,552	1,980,685
Italy	—	—	7,400	22,960
Japan	6,300	33,899	7,287	38,482
Netherlands	36,000	24,760	—	—
Mexico	15,506,833	9,210,192	11,798,625	6,938,072
United Kingdom	16	12,670	16	12,810
Total	18,447,958	11,348,848	14,853,880	9,044,683
Strontium nitrate:				
Italy	17,000	16,016	35,400	33,600
Korea, Republic of	—	—	1,000	4,500
Mexico	1,661,385	1,586,517	1,721,039	1,702,576
Spain	36,000	30,618	18,000	17,280
Total	1,714,385	1,633,151	1,775,439	1,757,956

¹Customs value.

Source: Bureau of the Census.

TABLE 6
WORLD STRONTIUM
CARBONATE ANNUAL
PRODUCTION CAPACITY,
DECEMBER 31, 1991

(Metric tons)

Country	Rated capacity ¹
North America:	
Mexico	87,000
United States ^{2 3}	22,000
Total	109,000
Europe:	
Germany ²	15,000
Spain	8,000
U.S.S.R.	(⁴)
United Kingdom	(⁴)
Total	23,000
Asia:	
China	1,800
Japan ²	31,000
Korea, Republic of	40,000
Total	72,800
World total	204,800

¹Included capacity at operating plants as well as plants on a standby basis.

²Production was entirely from imported celestite.

³Includes strontium nitrate production capacity.

⁴Strontium carbonate production capacity existed in these countries, but specific data were not available.

TABLE 7
STRONTIUM MINERALS: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991 ³
Algeria ⁴	5,400	5,400	5,400	5,400	5,400
Argentina	1,349	2,241	1,193	*1,200	1,200
Cyprus (celestite)	6,300	—	—	—	—
Iran (celestite) ³	*20,066	*39,194	*56,849	*34,140	40,000
Italy	177	—	—	—	—
Mexico (celestite)	47,739	51,626	*67,658	*66,254	*66,956
Pakistan	1,114	488	956	*1,799	1,800
Spain	28,867	*45,631	*40,000	*40,000	40,000
Turkey (celestite)	49,000	54,000	*59,000	*60,000	60,000
United Kingdom	22,655	25,553	20,885	24,734	25,000
Total	*182,667	*224,133	*251,941	*233,527	240,356

¹Estimated. ²Revised.

³Table includes data available through May 18, 1992.

⁴In addition to the countries listed, China, Poland, and the U.S.S.R. produce strontium minerals, but output is not reported quantitatively, and available information is inadequate to make reliable estimates of output levels.

⁵Data are for year beginning Mar. 21 of that stated.

⁶Reported figure.

SULFUR

By Joyce A. Ober

Mrs. Ober, a physical scientist with 14 years of industry and U.S. Bureau of Mines experience, has been a commodity specialist since 1986. Domestic survey data were prepared by Pamela G. Shorter, statistical assistant; and the international production table was prepared by staff, International Data Section.

Sulfur, through its major derivative sulfuric acid, ranks as one of the more important elements utilized by humanity as an industrial raw material. It is of prime importance to every sector of the world's industrial and fertilizer complexes. Sulfuric acid consumption has been regarded as one of the best indexes of a nation's industrial development.

The United States retained its position as the world's foremost producer and consumer of sulfur and sulfuric acid in 1991. Production of recovered elemental sulfur, a nondiscretionary byproduct of petroleum refining and natural gas processing, continued to increase and set a record-high production standard. Production from U.S. Frasch mines decreased to about 2.9 million metric tons, a 23% drop due primarily to the closing of two mines during the year.

Construction neared completion on the structures necessary to recover sulfur from a major salt dome on Federal lease block Main Pass 299 in the Gulf of Mexico. Rights to develop this deposit were acquired from the U.S. Department of the Interior in 1988. Main Pass 299 was the first new domestic Frasch mine to be built in more than 20 years.

Recovered elemental sulfur shipments to domestic consumers were greater than Frasch shipments. Recovered sulfur exports, primarily from California where sulfur supplies exceeded local demands, were higher than Frasch sulfur exports.

Byproduct sulfuric acid from the Nation's nonferrous smelters and roasters, essentially mandated by laws concerning sulfur dioxide (SO₂)

emissions, supplied a significant quantity of sulfuric acid to the domestic merchant acid market. Marketing sulfuric acid continued to be difficult for some producers because smelters were near western copper mines and far from major sulfuric acid markets.

Total world production of sulfur in all forms decreased about 4% compared with that of 1990; worldwide Frasch sulfur output decreased significantly because of the Gulf War, reduced output in the United States, production problems in Poland, and political turmoil in the former U.S.S.R. Recovered elemental production increased in Asia, Eastern Europe, and North America, decreased slightly in Western Europe because of declining production from gas plants, and remained about the same in the rest of the world. Almost five-eighths of the world's elemental sulfur production came from recovered sources; the quantity of sulfur supplied from these sources was dependent on the world demand for fuels and petroleum products, not on the demand for sulfur.

World sulfur consumption decreased slightly, with little change in the amount used for fertilizer production. Consumption for a myriad of industrial uses continued to be pressured by environmental constraints placed on the products produced or effluents from the chemical processes utilizing sulfur or its major derivative, sulfuric acid.

World trade of elemental sulfur decreased by an estimated 1.6 million metric tons, about 10% below levels recorded in 1990. Although individual country sulfur inventories showed

important variations from yearend 1990, total world producers' stocks of elemental sulfur remained about the same. (See table 1 and figure 1.)

DOMESTIC DATA COVERAGE

Domestic production data for sulfur are developed by the U.S. Bureau of Mines from four separate, voluntary surveys of U.S. operations. Typical of these surveys is the "Elemental Sulfur" survey. Of the 175 operations to which a survey request was sent, all responded, representing 100% of the total production shown in tables 1 and 2.

BACKGROUND

Sulfur, also known as brimstone, "the stone that burns," was used in small quantities for thousands of years. Ancient people were probably first drawn to native sulfur by its bright yellow color and pungent odor. Early humanity used sulfur as a colorant for cave drawings, as a fumigant, for medicinal purposes, and as incense. As early as 2000 B.C., the Egyptians used sulfur in the bleaching of linen textiles. In the *Odyssey*, Homer refers to its use as a fumigant. During the Peloponnesian War, fifth century B.C., the Greeks burned a sulfur-pitch mixture to generate suffocating gases. The Romans combined brimstone with tar, pitch, and other combustible materials to produce the first incendiary weapons. Muslims during the "Golden Age of Arabic Science," from about A.D. 700, developed alchemy and were probably the first producers of sulfuric

acid. Sulfur is a necessary ingredient in gunpowder, which was developed as a pyrotechnic in China by the 10th century. Gunpowder's introduction into Europe led to its use in warfare in the 14th century and made sulfur an important mineral commodity for the first time.

However, it was not until the birth of the science of chemistry in the 1700's and the growth of chemical industries in the 1800's that sulfur became of major importance to the world outside of its use in warfare. Early chemists soon recognized the importance of sulfuric acid as the cheapest and most versatile of the mineral acids, and it rapidly became and remains the most common acid in the chemical industry.

Sulfur is one of the few elements that occurs in the native, or elemental, state. It also occurs combined with iron and base metals as sulfide minerals, and with the alkali metals and alkali earths as sulfate minerals. In petroleum, sulfur is found in a variety of complex organic compounds, and in natural gas as hydrogen sulfide (H_2S) gas. In coal, sulfur occurs in complex organic compounds and as "coal brasses" (pyrites-marcasite). Commercial production of sulfur in the United States is accomplished by a variety of methods dictated by the source of sulfur.

Definitions, Grades, and Specifications

Bright Sulfur.—Crude sulfur free of discoloring impurities and bright yellow in color.

Brimstone.—Synonymous with crude sulfur.

Broken Sulfur.—Solid crude sulfur crushed to minus 8-inch size.

Crude Sulfur.—Commercial nomenclature for elemental sulfur.

Dark Sulfur.—Crude sulfur discolored by minor quantities of hydrocarbons ranging up to 0.3% carbon content.

Elemental Sulfur.—Processed sulfur in the elemental form produced from native sulfur or combined sulfur sources, generally with a minimum sulfur content of 99.5%.

Frasch Sulfur.—Elemental sulfur produced from native sulfur sources by the Frasch mining process.

Native Sulfur.—Sulfur occurring in nature in the elemental form.

Prilled Sulfur.—Solid crude sulfur in the form of pellets produced by cooling molten sulfur with air or water.

Pyrites.—Iron sulfide minerals that include pyrite, marcasite, and pyrrhotite.

Recovered Sulfur.—Elemental sulfur produced from combined sulfur sources by whatever method.

Slated Sulfur.—Solid crude sulfur in the form of slatelike lumps produced by allowing molten sulfur to solidify on water-cooled, moving belt.

Sulfur Ore.—Unprocessed ore containing native sulfur.

Sulfuric Acid.—Sulfuric acid of commerce produced from all sources of sulfur, generally reported in terms of 100% H_2SO_4 with a 32.69% sulfur content.

Products for Trade and Industry

Elemental sulfur of commerce, sometimes called crude sulfur or brimstone, may be marketed in either the liquid or the solid phase, generally with a minimum sulfur content of 99.5%. Most elemental sulfur marketed in North America is sold as liquid sulfur. In worldwide commerce, sulfur is shipped either as broken sulfur or formed sulfur. Formed sulfur—prills, slates, and pastilles—is generally preferred to broken sulfur because it is less prone to dusting and the release of fugitive dust at terminals where sulfur is stored and

transferred from one transportation mode to another. Sulfuric acid may be sold at various strengths, usually depending on the requirements of the consumer. The acid is generally marketed on a 100% basis, but is normally shipped at 66° Baume (93% H_2SO_4), as 98% acid, or as 20% to 22% fuming oleum, which is sulfur trioxide dissolved in sulfuric acid.

Industry Structure

Over the centuries, many fundamental changes have occurred in the sources of sulfur supply. Early civilizations obtained their meager requirements from native sulfur deposits in or around volcanoes. The increase in demand for sulfur in the late 1700's and early 1800's was largely satisfied from extensive native sulfur deposits in Sicily. Monopolistic practices by the owners of sulfur-mining facilities in Sicily led to exorbitant sulfur prices, causing consumers to adopt iron pyrites as the second major sulfur source during the mid- to late-19th century. The development in 1895 of the Frasch process for mining the large native deposits associated with salt domes in Louisiana and Texas brought a new and important source of sulfur to the United States and world markets. Frasch sulfur and pyrites maintained their joint predominance as world sulfur sources through the mid-1970's.

With small beginnings in the 1930's and increasing significantly from the 1950's onward, environmentally mandated or involuntary sulfur recovered during natural gas processing and petroleum refining grew to surpass Frasch sulfur and pyrites as the world's major source of sulfur. In addition, increasing quantities of byproduct sulfuric acid from smelting operations have been produced to comply with pollution control laws and environmental regulations worldwide.

Sulfur in its various forms is produced worldwide, with no single nation predominating as a producer or supplier to world markets. In 1991, world sulfur production and consumption amounted to 55.6 and 57.6 million tons, respectively. The United States and the U.S.S.R. were

the world's largest producers and consumers; both nations, however, were net importers of sulfur. Canada and Poland, respectively, the third and fifth largest world producers, ranked first and second among the world's exporting nations. China, the world's fourth largest producer and largest pyrites producer, was the third largest sulfur consumer; China, however, satisfied most of its sulfur requirements from internal sources.

Geology-Resources

Sulfur is widely distributed in nature, constituting 0.060% of the Earth's crust. Sulfur combines with most other elements, except the inert gases and nitrogen. Practically all plant and animal life on Earth contains some sulfur. Only a very small portion of the world's sulfur resources occurs in sufficiently concentrated quantities to justify commercial extraction by mining or other recovery methods. Sulfur is one of the few substances found in nature in the elemental form; it also occurs combined with other elements as sulfides, sulfates, or organic compounds in sedimentary, metamorphic, and igneous rocks, as well as in all fossil fuels. By type, sulfur deposits are classified as follows:

Native (Elemental) Sulfur Deposits.—These include deposits (1) in anhydrite-limestone cap-rock on the top and flanks of salt domes, (2) in bedded anhydrite-gypsum evaporite basin formations, and (3) in unconsolidated volcanic deposits. In salt dome cap-rock and evaporite beds, the sulfur is believed to have been formed by hydrocarbon reduction of anhydrite, assisted by bacterial action. Volcanic sulfur was produced by the reaction between escaping hydrogen sulfide and sulfur dioxide.

Large deposits over salt domes are mined in the gulf coast regions of the United States and Mexico. Extensive deposits in evaporites are mined in west Texas, Iraq, Poland, and the U.S.S.R. Together, these deposits are by far the principal source of mined elemental sulfur, generally extracted by the Frasch

hot water process. Most volcanic sulfur occurrences are in the circum-Pacific belt. Volcanic sulfur deposits are locally important, but furnish only a minor portion of the world's sulfur supply.

Sulfide Deposits.—These include deposits of (1) ferrous sulfides (pyrite, marcasite, and pyrrotite) that, while they may contain minor quantities of nonferrous metals, are generally mined and processed for their sulfur content and (2) nonferrous metal sulfides, which are mined for their metal content and in the processing produce sulfur in the form of sulfuric acid. In order of importance from the quantity of acid produced, sulfide minerals of copper, lead, zinc, molybdenum, nickel, mercury, arsenic, antimony, and silver are the most noted in the nonferrous sulfide group.

Sulfate Deposits.—These included bedded deposits of anhydrite and gypsum. Although they are mined on a large scale worldwide for their mineral content, they represent one of the world's largest, yet virtually untapped sulfur resources. Existing technology can recover elemental sulfur from these sources, but the economics are presently unfavorable.

Natural Gas.—Hydrogen sulfide occurs as a component of natural gas in many parts of the world. To market this "sour" natural gas, the hydrogen sulfide must be removed and, consequently, as additional sour natural gas fields have been brought into production, elemental sulfur recovered from these fields has become a major source of the world sulfur supply. Major deposits of sour natural gas occur in western Canada, the Near East, and the U.S.S.R.; substantial deposits occur in the mountain and gulf coast regions of the United States, France, the Federal Republic of Germany, Mexico, and Venezuela.

Petroleum and Tar Sands.—Complex organic sulfur compounds occur as a component of petroleum and tar sands in a wide range of concentrations. In the refining of petroleum or bitumen from tar

sands, a portion of the sulfur is removed and recovered in the elemental form. Changing environmental regulations have required larger proportions of contained sulfur to be removed annually. The vast petroleum reserves of the Near East contain high percentages of sulfur, as do many of the recent discoveries in Mexico and off the U.S. west coast. Additionally, Canadian tar sands constitute a major sulfur resource.

Coal and Oil Shale.—Sulfur occurs as pyrites or complex organosulfur compounds in varying concentrations in both coal and oil shales. Although little sulfur is produced from these vast resources at present, the potential for large-scale output exists in the United States and in the rest of the world.

Economic Factors

During the past 20 years, world sulfur price leadership has shifted from dominance by the U.S. Frasch producers to the Canadian exporters. The transfer was aided in the 1980's by Canada's ability to export most of its production from the Port of Vancouver and by its willingness to ship large volumes of sulfur from vatted stocks. The maturation of Sultran Ltd., dealing almost exclusively with sulfur destined for the offshore market, into a well-organized and skilled transportation arm of the Canadian sulfur industry aided immeasurably in Canada's ascension to world price leadership.

In the United States, the quoted liquid Frasch sulfur price, f.o.b. terminal Tampa, FL, is the benchmark price. Recovered sulfur producers, in many cases, consider the economic desirability of producing sulfur subordinate to the necessity of producing it. As a result, domestic recovered elemental sulfur producers normally offer sulfur at a price \$5 to \$15 per ton below the Tampa quote to ensure prompt sale and reduce storage costs. This marketing strategy has resulted in restricting Frasch sulfur sales from many market areas that they formerly served.

During the 1980's, the sulfur price showed a significant degree of volatility compared with its prior history and the early years of the 1990's continued the trend. The worldwide recession of 1982 and the U.S. Department of Agriculture Payment In Kind program in 1983 reduced world sulfur production and demand. (See table 2.)

ANNUAL REVIEW

Production

Frasch.—Native sulfur associated with the cap-rock of salt domes and in sedimentary deposits is mined by the Frasch hot water method, in which the native sulfur is melted underground and brought to the surface by compressed air. In January 1991, the United States had five Frasch mines operating in Louisiana and Texas; two of the Louisiana mines ceased operation during the year. Freeport Sulphur Co. owned and operated three mines in Louisiana. The Caminada Pass mine 9 miles offshore in the Gulf of Mexico operated throughout the year. Garden Island Bay on the Mississippi River Delta and Grand Isle, 7 miles offshore, were closed during the year due to depletion of resources. Mines in Texas were Pennzoil Sulphur Co., at Culberson, and Texasgulf Inc. (TG), at Boling Dome in Wharton County.

In December 1988, Freeport McMoRan Resource Partners, operator for a consortium that included the IMC Fertilizer Group Inc. and Felmont Oil Co., reported a geologic reserve of 50 million long tons of sulfur on its Federal lease block, Main Pass 299, which is offshore in the Gulf of Mexico, 17 miles from the mouth of the Mississippi River. The announcement was based on the results of five exploratory holes. Additional drilling in 1989 delineated the size of the salt dome deposit and established the total reserve at 67 million long tons, which made Main Pass 299 the second largest domestic sulfur deposit yet discovered. Freeport McMoRan began construction on the offshore platform for the mine in 1990. The company expected to begin production at Main Pass 299 in

early 1992, reaching full capacity of about 2 million tons per year sometime in 1993. The project required an investment of more than \$550 million.

The shutdown of the two Freeport mines severely curtailed Frasch production. Frasch sulfur output decreased 860,000 tons from the quantity produced in 1990. Total shipments to domestic and overseas consumers decreased by more than 550,000 tons. Frasch sulfur accounted for 27% of domestic production in 1991. Approximately 86% of Frasch sulfur shipments was for domestic consumption; the remainder, for export. The total value of Frasch sulfur shipments decreased by more than \$63 million.

Recovered.—Recovered elemental sulfur, a nondiscretionary byproduct from petroleum refining, natural gas processing, and coking plants, was produced primarily to comply with environmental regulations that were applicable directly to emissions from the processing facility or indirectly by restricting the sulfur content of the fuels sold or used by the facility. Fuel processing plants accounted for 61% of the total domestic output of sulfur in all forms compared with 56% in 1990. Production and shipments of recovered sulfur reached alltime high levels owing to record production from the Nation's petroleum refineries. Production and shipments from natural gas processing plants remained at about the same level as that in 1991. Recovered elemental sulfur was produced by 58 companies at 151 plants in 26 States, 1 plant in Puerto Rico, and 1 plant in the U.S. Virgin Islands. Most of these plants were of relatively small size, with only 16 reporting an annual production exceeding 100,000 tons. By source, 64% was produced at 84 refineries or satellite plants treating refinery gases and 3 coking plants. The remainder was produced by 27 companies at 64 natural gas treatment plants. The five largest recovered-sulfur producers in 1990 were Exxon Co. U.S.A., Standard Oil Co. (California), Standard Oil Co. (Indiana), Shell Oil Co., and Mobil Oil Corp. The

54 plants owned by these companies accounted for 58% of recovered elemental sulfur output during the year. (See tables 3, 4, 5, 6, and 7.)

Byproduct Sulfuric Acid.—Byproduct sulfuric acid at copper, lead, molybdenum, and zinc roasters and smelters amounted to 12% of the total domestic production of sulfur in all forms. Eight acid plants operated in conjunction with copper smelters, and eight were accessories to lead, molybdenum, and zinc smelting and roasting operations. The five largest acid plants (all at copper mines) accounted for 72% of the output. The five largest producers of byproduct sulfuric acid were Phelps Dodge Corp., Magma Copper Co., ASARCO Incorporated, Kennecott Corp., and Cyprus Miami Mining Corp.

Their eight plants produced 85% of the 1990 total. (See table 8.)

Pyrites, Hydrogen Sulfide, and Sulfur Dioxide.—The total sulfur contained in these products did not constitute a significant portion of total domestic sulfur production. (See table 9 and figure 2.)

Consumption and Uses

Domestic consumption of sulfur in all forms was virtually the same in 1991 as it was in 1990. In 1991, 77% of the sulfur consumed was obtained from domestic sources compared with 80% in 1990 and 82% in 1989. The sources of supply were domestic recovered elemental sulfur, 46%; domestic Frasch sulfur, 21%; and combined domestic byproduct sulfuric acid, pyrites, hydrogen sulfide, and sulfur dioxide, 10%. The remaining 23% was supplied by imports of Frasch and recovered elemental sulfur.

The U.S. Bureau of Mines collected end-use data on sulfur and sulfuric acid according to the Standard Industrial Classification of industrial activities. Shipments by end use of elemental sulfur were reported by 60 companies, and shipments of sulfuric acid were reported by 52 companies. Shipments of both

elemental sulfur and sulfuric acid were reported by seven companies.

Sulfur differs from most other major mineral commodities in that its primary use is as a chemical reagent rather than a component of a finished product. Its predominant use as a chemical reagent generally required that it first be converted to an intermediate chemical product prior to its initial use by industry. The largest sulfur end use, sulfuric acid, represented 85% of shipments for domestic consumption. Some identified sulfur end uses were tabulated in the "Unidentified" category because these data were proprietary. Data collected from companies that did not identify shipment by end use were also tabulated as "Unidentified." Although there are no supporting data, it could be reasonably assumed that a significant portion of the sulfur in the "unidentified" category was shipped to sulfuric acid producers or was exported. The difference between exports reported in the canvass and exports of 1.12 million tons reported by the Bureau of the Census may have been caused by differences in accounting between company records and compilations by the Census Bureau, or by sales to other parties that exported sulfur and were not included in the U.S. Bureau of Mines canvass.

Sulfuric acid, because of its desirable properties, retained its position, both domestically and worldwide, as the most universally used mineral acid and the largest volume inorganic chemical in terms of the quantity produced and consumed. U.S. shipments of sulfuric acid (100% basis) decreased by about 700,000 tons in 1991 owing primarily to decreases in demand for the production of phosphoric acid, the largest single end use. Sulfuric acid demand for copper ore leaching, the second largest end use, increased about 150,000 tons to 2.1 million tons as reported by sulfuric acid producers because solvent extraction-electrowinning (SX-EW) operations could produce high-purity copper at a significantly lower cost than by conventional smelting methods. Reported shipments of sulfuric acid for petroleum refining and other petroleum and coal

products were not significantly different from those of 1990.

According to the 1991 canvass reports, company receipt of spent or contaminated sulfuric acid for reclaiming totaled 3.2 million tons. The largest source of this spent acid continued to be the petroleum refining industry, which accounted for 51% of the total returned. About 0.9 million tons of spent acid was reclaimed from plastic and synthetic materials producers. The remaining reclaimed acid was from manufacturers of inorganic pigments, copper ores, other chemical products, industrial organic chemicals, phosphatic fertilizers, explosives, and some unidentified sources.

The largest use of sulfur in all forms, for agricultural purposes, decreased from 9.2 million tons in 1990 to about 9.0 million tons. The estimated quantity of sulfur needed to manufacture exported agricultural chemicals increased by more than about 70,000 tons to 4.6 million tons, indicating that consumption for domestic purposes, especially for phosphatic fertilizers, decreased by more than 150,000 tons. (See tables 10, 11, 12, 13, and 14 and figures 3 and 4.)

Stocks

Yearend inventories held by Frasch and recovered elemental sulfur producers decreased 16% from those of 1990, indicating a tightness of supply. Combined yearend stocks amounted to approximately a 44-day supply compared with a 51-day supply in 1990, a 46-day supply in 1989, a 38-day supply in 1988, and an 86-day supply in 1987 based on domestic and export demands for Frasch and recovered sulfur. (See table 15.)

Markets and Prices

The posted price for liquid sulfur exterminal Tampa, FL, began the year at \$140 per long ton and remained at that level until the middle of June when it dropped to \$125, the \$15 drop being the largest single price change in Frasch history. The Tampa price dropped another \$15 to \$110 at the beginning of August and to \$98 at the beginning of

November. Such dramatic changes in the price situation were unexpected. A shortage of sulfur supply was expected because of the closing of two U.S. mines as well as the damage sustained to the Kuwaiti and Iraqi sulfur operations as a result of the war in the Persian Gulf. The oil refineries in Kuwait were nearly destroyed by the Iraqi army, and although Iraqi Frasch operations were not believed to be significantly damaged, the trade sanctions against Iraq imposed by the United Nations Security Council remained in effect, which essentially removed the annual 1.5- to 1.7-million-ton Iraq-Kuwait sulfur exports from international commerce.

However, Canadian sulfur exporters, hard hit by low natural gas prices, slashed their sulfur prices to establish markets in areas traditionally supplied by Frasch producers. The posted Frasch Tampa price decreases of 30% were a direct attempt by the domestic Frasch producers to maintain market share and to reduce the Canadian influence in the U.S. market.

On the basis of total shipments and value reported to the U.S. Bureau of Mines, the average value of shipments of Frasch sulfur, f.o.b. mine, for domestic consumption and exports combined decreased from \$91.17 to \$87.05 per ton. The average value, f.o.b. plant, for shipments of recovered elemental sulfur varied widely by geographic region, with reported values by State averaging anywhere from a low of about \$38 per ton to about \$88 per ton. The national average value for the year was about \$64 per ton, almost \$10 per ton less than the average for 1990. (See table 16.)

Foreign Trade

Exports of elemental sulfur from the United States, including the U.S. Virgin Islands, increased 23% in quantity and increased 9% in value. According to the Bureau of the Census, exports from the west coast were 641,000 tons or 54% of total U.S. exports.

The United States continued to be a net importer of sulfur; imports exceeded exports by more than 1.8 million tons in

1991. Frasch sulfur from Mexico and recovered elemental sulfur from Canada, both delivered to U.S. terminals and consumers in the liquid phase, furnished 97% of all U.S. sulfur import requirements. Total elemental sulfur imports increased 17% in quantity; imports by rail from Canada increased 17%, while waterborne shipments from Mexico were 12% higher than those in 1990. Imports from other sources, while still very small compared to those from Canada and Mexico, increased 400%.

The United States also had significant trade in sulfuric acid. Sulfuric acid exports decreased about 8% from those of 1990. Imports, which were significantly greater than exports, were mostly by rail from Canada. The tonnage increased 9% from the quantity reported in 1990; the value of imported sulfuric acid, however, decreased 8%. Approximately 554,000 tons of acid was imported into the Tampa, FL, area, about 6% more than the Tampa acid imports of the previous year. Two sulfuric acid terminals had been established there in 1989. (See tables 17, 18, 19, and 20.)

World Review

The volatility of the world political and economic situation was reflected in events in the sulfur industry in 1991. Early in the year, the tenuous situation in the Middle East raised concerns over the possible shortage of sulfur for the world market and possibly large price increases. Price increases never occurred; in fact, prices fell precipitously through the second half of the year. The eventual military action did cause significant damage to the petroleum industry in Kuwait and Iraq, but the shortages from those countries were compensated for by increased production in other countries and shipments from stockpiled material.

The political and economic climates in Eastern Europe remained changeable, and the situation was not expected to be resolved quickly. Industry has experienced serious setbacks, and until the economic problems ease, demand for sulfur in the region will be low. The poor economic conditions also have a

more widespread impact owing to decreased demand for imported fertilizers, which in turn lessens the need for sulfur in countries that would normally have supplied that fertilizer.

With the abolition of the Communist party in the U.S.S.R. in August, the same type of situation arises there as in Eastern Europe. The economy is extremely weak, and the political situation is unstable. Stability, both economic and political, in the region may take many years to achieve.

Industry Structure.—In 1991, the sulfur industry was divided into two sectors, discretionary and nondiscretionary. In one, the mining of sulfur or pyrites was the sole objective; this voluntary production of native sulfur or pyrites was based on the orderly mining of discrete deposits, with the objective of obtaining as nearly a complete recovery of the resource as economic conditions permit. In the other, sulfur or sulfuric acid was recovered as an involuntary byproduct, the quantity of output subject to demand for the primary product irrespective of sulfur demand. In 1991, involuntary sources represented almost 60% of the elemental sulfur produced worldwide.

Large quantities of Frasch sulfur were produced from mines in only five countries: Iraq, Mexico, Poland, the U.S.S.R., and the United States. Poland and the U.S.S.R. also produced significant quantities of native sulfur using conventional mining techniques; small quantities of native sulfur were produced in Asia, Europe, and South America. Pyrites were the prime sulfur source in China, Spain, and the Republic of South Africa and an important source in Scandinavia and the U.S.S.R.

Recovered elemental sulfur was the predominant sulfur source in Canada, France, the Federal Republic of Germany, Saudi Arabia, and the United States. Additionally, recovered elemental sulfur was an important source in Iran, Japan, and the U.S.S.R. Due to the Gulf War, sulfur production in Iraq and Kuwait was significantly less than that in previous years. Production levels in

these countries were not expected to fully recover in this century.

International sulfur trade was dominated by a limited number of exporting countries; exports from Canada, Poland, Saudi Arabia, Mexico, the United States, and the Federal Republic of Germany, in descending order of the quantity shipped, accounted for 93% of sulfur trade in 1991. Major sulfur importers in 1991 were the United States, Morocco, India, Tunisia, Brazil, the U.S.S.R., France, the Republic of Korea, and the United Kingdom, in descending order of importance.

Capacity.—The data in table 21 are rated capacity for Frasch mines, elemental sulfur mining facilities and attendant beneficiation plants, pyrites mines and plants, sulfur and/or sulfuric acid recovery units associated with petroleum refineries, natural gas processing plants, metal smelting operations, electric powerplants, and coke ovens as of December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the facility, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with a minimum of capital expenditure. Rated capacity is not equivalent to engineering (design) capacity of installed equipment.

Frasch mines operate continuously, and capacity is related to the quantity of superheated water that can be injected into the associated sulfur deposit. The nature of Frasch mining makes capacity quite variable over time and depends on the number of "steaming wells," water injection rates, water losses from the formation, location of wells within the deposit, and length of time that the deposit has been worked. The rated capacity or realizable capacity of a Frasch

mine generally decreases as the deposit becomes depleted.

Petroleum refineries—large, very costly, and complex processing facilities designed to produce a spectrum of fuels and petrochemical products—operate continuously. Sulfur recovery units make up only a small segment of these facilities; because sulfur recovery is mandated by environmental considerations, the installed sulfur recovery capacity at petroleum refineries generally exceeds the expected sulfur production. To ensure that the loss of a sulfur recovery unit does not require the shutdown of the entire refinery, multiple sulfur recovery units, each capable of servicing the petroleum refinery, are installed. The quantity of sulfur recovered by domestic petroleum refineries in the United States during 1991 was equal to slightly more than 50% of the installed engineering capacity. Rated capacity for petroleum refineries is assumed to be 50% of installed engineering capacity.

Natural gas processing plants may be installed to service gasfields and/or oilfields that contain significant quantities of associated gas. Gas plants are designed to accommodate the natural gas from a specific field that may contain in addition to methane, which is sold as pipeline gas, varying amounts of nitrogen, carbon dioxide, helium, condensable hydrocarbon liquids, and poisonous hydrogen sulfide. The poisonous nature of hydrogen sulfide makes its removal from pipeline gas imperative. Sulfur removal and recovery plants in natural gas facilities vary in size from small units rated at 5 to 10 tons per day to multiple-train plants capable of recovering thousands of tons per day. In general, sulfur recovery rates from gasfields approximate installed engineering capacity, based on a 340- to 345-day-per-year operation of all units, in the first 7 years of operation. In succeeding years, sulfur recovery declines steadily because the gas apparently becomes "sweeter" over time and because gas flow rates drop as the field is depleted. Rated capacity for gas processing plants is based on the age of

the plant and its recent production history.

Rated capacity for plants operating in conjunction with metal smelters, powerplants, and coking operations is assumed to approximate engineering capacity. Where information on design capacity is unknown, rated capacity was estimated to be equal to the greatest output recorded by a plant or country in the past 5 years. World rated sulfur annual production capacity is significantly lower than the installed world engineering capacity of approximately 91 million tons. (See table 21.)

Canada.—The world's leading sulfur exporting country experienced a setback in its offshore sales, but because of increased sales to the United States, Canadian exports were about the same in 1991 as they were in 1990. Production in Canada was 6.23 million tons, 5.8% higher than that in the previous year. Sulfur recovered from natural gas processing represented 87.6% of total Canadian production, with 8.7% from oil sand and 3.7% from oil refining.

The majority of Canadian sulfur is produced in Alberta and British Columbia. With the completion of Shell Canada's Caroline natural gas recovery project in Alberta, an additional 1.5 million tons of sulfur capacity should be operational by early in 1993. An estimated 25 million tons of sulfur is contained in this deposit, which has an average H₂S content of 35.3%.

Shell was also completing a project to determine the feasibility of producing sulfur from a deposit containing more than 90% H₂S as well as elemental sulfur. The Bearberry sulfur reserves are estimated at 40 million tons, and because of the corrosiveness of the material, presented significant challenges to designing a successful recovery process. Materials were developed, and the pilot project proved successful, but the cost of construction of a full-scale plant would be prohibitive, especially with sulfur prices at current lows.

At yearend, a group of 27 Canadian sulfur producers formed a new marketing organization to sell sulfur outside North

America. Named Prism Sulphur Corp., the group should temper the fierce competition among Canadian producers and in so doing establish a more stable pricing structure.

Iraq.—Iraq's Frasch sulfur operation was not believed to have been damaged during the war in the Persian Gulf, but sulfur production and exports remained very low due to the United Nation's trade embargo that was instituted after Iraq invaded Kuwait in early August 1990. The embargo was to remain in effect until Iraq complied with all the conditions in the United Nations ceasefire agreement. U.N. inspectors were still attempting to verify compliance at yearend with little cooperation from Iraq.

Kuwait.—In the aftermath of the Gulf War, fires set by retreating Iraqi troops raged at 749 oil wells. Projections at the time estimated that years of firefighting would be required for all the fires to be extinguished. Due to a heroic international effort, the last well fire was put out on November 6, 1991, less than 7 months after the cease-fire agreement. The effects of the environmental devastation will be felt for years to come, but the immediate emergency passed, enabling the Kuwaiti Government to begin the rebuilding process. The Kuwaiti Government was in the position to get started with reconstruction, possessing cash sufficient to begin. Oil production and refining in Kuwait resumed by the end of the year, with sulfur recovery expected early in 1992.

Mexico.—Frasch sulfur production decreased 24% from 1990 to about 1.1 million tons. Exports to the United States increased to replace the Frasch sulfur shortages experienced with the closing of the Freeport mines, although total exports decreased. More than 55% of the sulfur produced in Mexico is from Frasch deposits. Serious technical problems occurred at the Coachapa/Otopan and the Jaltipan Mines, raising questions as to the future of those mines.

Morocco.—Morocco was a major world importer of elemental sulfur because of consumption at its phosphate fertilizer facilities at Safi and Jorf Lasfar. Imports were about 2.07 million tons in 1991, a 13% decrease from approximately 2.38 million tons imported in 1991.

Poland.—Economic problems in Eastern Europe and the U.S.S.R. have taken their toll on the Polish sulfur industry. In the past, the majority of Polish sulfur exports was to this region, but Polish exports in 1991 were about 2.9 million tons, 24% less than those in 1990. Although efforts were made to sell Polish sulfur in new markets, high production costs made it difficult to compete in current market conditions, and inventories grew.

Poland was the largest world producer of native sulfur, with major mines at Jeziorko, Grzybow, and Machow. The construction of the new Osiek Mine was beset by financial problems, but production was expected to begin there late in 1992. The mine should come on-stream in two phases, one in 1992 and the second in 1993.

U.S.S.R.—Production of sulfur in all forms decreased substantially for the fourth consecutive year. Political events that precipitated the dissolution of the Communist party, have pushed the region to a market economy. The majority of sulfur in the former U.S.S.R. was produced in Kazakhstan, Russia, Turkmenistan, and the Ukraine. Three Frasch mines were operated in the Ukraine and one in Turkmenistan. Technical and economic problems with the Frasch operations suggested that production will continue at reduced levels in the immediate future.

The former U.S.S.R. was believed to contain huge oil and gas reserves that had not yet been tapped. Operating refineries were in Kazakhstan (Tengiz), Russia (Astrakhan and Orenburg), and Uzbekistan (Mubarek), but not to their full potential. The Tengiz oil and gas processing plant began production at

Tengiz I, the first phase of construction, but adjustments were necessary immediately owing to higher than expected sulfur content. Tengiz II and Tengiz III were expected to begin operation in 1992 and 1993, respectively. (See table 22.)

OUTLOOK

Discussing the outlook for the sulfur industry is much like predicting the outcome of the political and economic upheaval occurring throughout the world—it is very difficult if not impossible. The future of the sulfur industry is closely tied to world economy, which in turn is very dependent on the political climate. With events in the Middle East and Eastern Europe only beginning to sort themselves out, it may be several years before predictions can be made with any degree of confidence.

However, at least one fact is certain—sulfur will continue to be produced throughout the world for all of the foreseeable future, and the volume of production will continue to increase. Demand, however, may not. Environmental concerns and legislation reflecting those concerns will mandate increasingly large proportions of sulfur to be recovered from effluent streams, as elemental sulfur, sulfuric acid, or sulfur in other forms. But similar environmental concerns will continue to play a part in determining areas for sulfur consumption. In many cases, processes dependent on sulfur and/or sulfuric acid have been changed to eliminate sulfur requirements and replace it with materials that are perceived as less damaging to the environment.

World sulfur demand, from 1992 to 1996, is forecast to increase at an annual rate of less than 1% per year. From 1996 to the year 2000, growth is expected to be higher at almost 2%. World demand is projected to attain 59.1 million tons in 1995 and increase to more than 65 million tons in the year 2000. In the short term, U.S. sulfur demand is forecast to increase from 12.9 million tons consumed in 1991 to 13.7 million

tons in 1995 and 14.2 million tons in the year 2000.

Almost two-thirds of sulfur consumption in the United States is for agricultural uses. More than 90% of U.S. agricultural sulfur demand and almost 80% of world agricultural sulfur consumption was for the manufacture of phosphoric acid in 1991. World demand for phosphate fertilizers is forecast to increase at an annual rate of about 1.5% for the next 10 years. It is assumed that 90% of the growth will be for the production of phosphoric acid to produce high-analysis fertilizers, which will directly affect world sulfur demand. Consumption of sulfur for phosphate fertilizer manufacture in the United States is divided into two main components: (1) demand for phosphate fertilizers consumed by domestic farmers and (2) demand for exported phosphate fertilizers.

In 1991, an estimated 4.6 million tons of sulfur was required to manufacture the phosphatic fertilizers exported from the United States compared with 3.7 million tons of sulfur for domestic phosphoric fertilizer use. Sulfur demand for domestically consumed phosphates is forecast to increase to almost 4.8 million tons by 1995 and remain relatively stable thereafter. However, the situation in Eastern Europe and the former U.S.S.R. raises questions about fertilizer consumption for the rest of this century. It may take until the beginning of the next century before these economies stabilize and trends in fertilizer consumption become more predictable.

The broad spectrum industrial or nonagricultural sulfur use category accounted for almost 33% of U.S. sulfur consumption and about 42% of world sulfur demand. While significant variations in demand for the diverse elements within this broad category are expected in the United States and other geographic areas, world industrial demand is expected to average less than a 1% increase annually through the remainder of the century, reaching 25 million tons in the year 2000.

The necessity for the removal of sulfur from solid, liquid, and gaseous effluents

for environmental protection has caused the production of sulfur and sulfur compounds from these sources to exceed production from primary sources of supply. The long-term prospect is that 85% or more of the world sulfur supply will come from environmentally regulated sources and that output from these sources will be produced regardless of world sulfur demand. As a result, it is probable that, after the turn of the century, no new operation that produces sulfur as its primary product will be developed, except where it may be deemed necessary for political or social reasons. In 1980, voluntary sources of production, Frasch, native sulfur, and pyrites, accounted for 50% of world output of about 55 million tons. In 1991, these same sources supplied only 40% of world production of 55.6 million tons. (See table 23.)

It is anticipated that, in the short term, world sulfur supply and demand will be closely balanced, but a number of new production facilities that will be completed soon, are under development, or in the planning stage will create tremendous new supply sources. In Canada, projects nearing completion should raise output from existing gas plants 400,000 to 500,000 tons by 1992. The development of the Caroline Gasfield should increase Canadian capacity by 1.2 million tons in 1993. The development of a new mine in Poland and new associated gas processing facilities in the former U.S.S.R. are currently behind schedule, but upon completion could add an additional 5.3 million tons of production capacity. Freeport McMoRan plans to have its new Main Pass 299 Mine on-stream by early 1992 and be producing at a rate of more than 2 million tons per year by 1993 or early 1994, increasing U.S. Frasch capability almost 1 million tons compared with that of 1990 and 2 million tons more than that in 1991. Net additions to world production from expansions and new facilities at oil refineries and gas processing plants should amount to several hundred thousand tons. A worldwide sulfur surplus will probably develop in 1993, a surplus that could

persist for much of the remainder of the century. World sulfur production may attain a level of 62 million tons in 1995 and exceed 66 million tons in the year 2000.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

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TABLE 1
SALIENT SULFUR STATISTICS

(Thousand metric tons, sulfur content, and thousand dollars unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Production:					
Frasch	3,202	3,174	3,888	3,726	2,869
Recovered ¹	6,161	6,444	6,510	6,536	6,645
Other forms	1,176	1,128	1,194	1,298	1,306
Total	10,539	10,746	11,592	11,560	10,820
Shipments:					
Frasch	3,610	4,341	3,780	3,676	3,120
Recovered ¹	6,180	6,470	6,475	6,483	6,682
Other forms	1,176	1,128	1,194	1,298	1,306
Total	10,966	11,939	11,449	11,457	11,108
Exports, elemental ²	1,242	1,223	1,024	972	1,196
Imports, elemental	1,599	1,996	2,260	2,571	3,020
Consumption, all forms	11,323	12,712	12,685	13,056	12,932
Stocks, Dec. 31: Producer, Frasch and recovered	2,316	1,112	1,301	1,423	1,194
Value:					
Shipments, f.o.b. mine or plant:					
Frasch	\$386,834	\$430,814	\$378,712	\$335,189	\$271,599
Recovered ¹	\$492,136	\$498,368	\$509,582	\$479,011	\$428,816
Other forms	\$90,707	\$88,181	\$104,304	\$117,139	\$112,218
Total	\$969,677	\$1,017,363	\$992,598	\$931,339	\$812,633
Exports, elemental ^{3 4}	\$139,431	\$131,863	\$107,126	\$109,327	\$120,134
Imports, elemental ⁴	\$152,096	\$185,864	\$209,465	\$206,450	\$241,826
Price, elemental, dollars per metric ton, f.o.b. mine or plant	\$89.78	\$85.95	\$86.62	\$80.14	\$71.45
World: Production, all forms (including pyrites)	*56,968	*59,117	*59,471	*58,154	*55,592

*Estimated. †Revised.

¹Includes Puerto Rico and the Virgin Islands.

²Includes exports from the Virgin Islands to foreign countries.

³Includes value of exports from the Virgin Islands to foreign countries.

⁴Declared customs valuation.

TABLE 2
TIME-PRICE RELATIONSHIPS
FOR SULFUR¹

Year	Actual prices	Based on constant 1991 dollars
1972	16.76	50.54
1973	17.56	49.75
1974	28.42	74.06
1975	44.91	106.81
1976	45.72	102.28
1977	44.38	92.89
1978	45.17	87.64
1979	55.75	99.58
1980	89.06	145.33
1981	111.48	165.31
1982	108.27	151.16
1983	87.24	117.05
1984	94.31	121.26
1985	106.46	131.95
1986	105.22	127.05
1987	89.78	105.04
1988	85.95	96.79
1989	86.62	93.49
1990	80.14	83.05
1991	71.45	71.45

¹Based on the average reported prices for elemental sulfur (Frasch and recovered), f.o.b. mine and/or plant, these prices reflect essentially 90% of the shipments of sulfur in all forms during 1972-91.

TABLE 3
PRODUCTION OF SULFUR AND SULFUR-CONTAINING RAW
MATERIALS IN THE UNITED STATES

(Thousand metric tons)

	1990		1991	
	Gross weight	Sulfur content	Gross weight	Sulfur content
Frasch sulfur	3,726	3,726	2,869	2,869
Recovered sulfur ¹	6,536	6,536	6,645	6,645
Byproduct sulfuric acid (100% basis) produced at copper, lead, molybdenum, and zinc plants	3,959	1,294	3,984	1,302
Other forms ²	8	4	10	4
Total	XX	11,560	XX	10,820

XX Not applicable.

¹Includes Puerto Rico and the Virgin Islands.

²Includes hydrogen sulfide, liquid sulfur dioxide, and pyrites.

TABLE 4
SULFUR PRODUCED AND SHIPPED FROM FRASCH MINES IN THE
UNITED STATES

(Thousand metric tons and thousand dollars)

Year	Production			Shipments	
	Texas	Louisiana	Total	Quantity	Value ²
1987	1,833	1,369	3,202	3,610	386,834
1988	1,991	1,183	3,174	4,341	430,814
1989	2,380	1,508	3,888	3,780	378,712
1990	2,303	1,424	3,726	3,676	335,189
1991	1,846	1,023	2,869	3,120	271,599

¹Data do not add to total shown because of independent rounding.

²F.o.b. mine.

TABLE 5
RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES¹

(Thousand metric tons and thousand dollars)

Year	Production			Shipments	
	Natural gas plants	Petroleum refineries ²	Total	Quantity	Value ³
1987	2,536	3,624	6,161	6,180	492,136
1988	2,501	3,943	6,444	6,470	498,368
1989	2,537	3,973	6,510	6,475	509,582
1990	2,336	4,200	6,536	6,483	479,011
1991	2,402	4,242	6,645	6,682	428,816

¹Includes Puerto Rico and the Virgin Islands.

²Includes a small quantity from coking operations.

³F.o.b. plant.

⁴Data do not add to total shown because of independent rounding.

TABLE 6
RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1990			1991		
	Production	Shipments		Production	Shipments	
		Quantity	Value		Quantity	Value
Alabama	375	375	33,056	362	360	29,928
California	697	700	38,705	714	720	27,210
Florida	55	55	W	37	37	W
Illinois	260	260	20,894	240	240	17,485
Louisiana	669	665	61,434	692	692	61,123
Michigan and Minnesota	185	185	14,369	174	174	12,402
Mississippi	727	715	48,606	695	686	45,710
New Mexico	48	48	2,989	54	54	2,774
North Dakota	109	110	6,368	88	89	4,382
Ohio	46	47	4,245	48	48	3,941
Pennsylvania	70	70	3,711	66	66	3,446
Texas	1,653	1,645	142,100	1,733	1,735	113,118
Wyoming	944	938	44,568	1,074	1,072	50,355
Other ¹	700	671	57,968	669	711	56,942
Total²	6,536	6,483	479,011	6,646	6,684	428,816

W Withheld to avoid disclosing company proprietary data; included with "Other."

¹Includes Arkansas, Colorado, Delaware, Indiana, Kansas, Kentucky, Montana, New Jersey, Utah, Virginia, Washington, Wisconsin, Puerto Rico, the Virgin Islands, and data indicated by symbol W.

²Data may not add to totals shown because of independent rounding.

TABLE 7
RECOVERED SULFUR PRODUCED AND SHIPPED
IN THE UNITED STATES,
BY PETROLEUM ADMINISTRATION FOR
DEFENSE (PAD) DISTRICT

(Thousand metric tons)

District and source	1990		1991	
	Production	Shipments	Production	Shipments
PAD 1:				
Petroleum and coke	306	305	302	304
Natural gas	55	55	37	37
Total¹	362	361	338	340
PAD 2:				
Petroleum and coke	674	675	653	653
Natural gas	110	110	90	89
Total¹	784	786	743	742
PAD 3:²				
Petroleum	2,329	2,287	2,402	2,440
Natural gas	1,241	1,234	1,213	1,213
Total¹	3,571	3,521	3,615	3,653
PAD 4 and 5:				
Petroleum	890	892	886	886
Natural gas	929	924	1,064	1,062
Total	1,820	1,816	1,950	1,948
Grand total¹	6,536	6,483	6,646	6,684

¹Data may not add to totals shown because of independent rounding.

²Includes Puerto Rico and the Virgin Islands.

TABLE 8
BYPRODUCT SULFURIC ACID¹ PRODUCED IN THE UNITED STATES

(Thousand metric tons, sulfur content, and thousand dollars)

Year	Copper plants ²	Zinc plants ³	Lead and molybdenum plants ³	Total	Value
1987	831	134	38	1,003	\$61,996
1988	946	136	43	1,125	87,820
1989	1,005	134	51	1,190	103,526
1990	1,105	135	54	1,294	116,356
1991	1,101	137	64	1,302	106,891

¹Includes acid from foreign materials.

²Excludes acid made from pyrites concentrates.

³Excludes acid made from native sulfur.

TABLE 9
PYRITES, HYDROGEN SULFIDE, AND SULFUR DIOXIDE SOLD OR
USED IN THE UNITED STATES

(Thousand metric tons, sulfur content, and thousand dollars)

Year	Pyrites	Hydrogen sulfide	Sulfur dioxide	Total	Value
1987	W	W	W	173	\$28,711
1988	W	W	W	3	361
1989	W	W	—	4	778
1990	W	W	—	4	783
1991	W	W	—	4	776

W Withheld to avoid disclosing company proprietary data; included in "Total."

TABLE 10
CONSUMPTION OF SULFUR¹ IN THE UNITED STATES

(Thousand metric tons)

	1987	1988	1989	1990	1991
Frasch:					
Shipments	3,610	4,341	3,780	3,676	3,120
Exports	465	464	330	348	448
Imports	793	1,079	1,086	1,129	1,259
Total	3,938	4,956	4,536	4,457	3,931
Recovered:					
Shipments ²	6,180	6,470	6,475	6,483	6,682
Exports	777	759	694	624	748
Imports	806	917	1,174	1,442	1,760
Total	6,209	6,628	6,955	7,301	7,694
Total elemental	10,147	11,584	11,491	11,758	11,625
Pyrites, shipments	W	W	W	W	W
Byproduct sulfuric acid, shipments	1,003	1,125	1,190	1,294	1,302
Other forms, shipments ³	173	3	4	4	4
Total, all forms	11,323	12,712	12,685	13,056	⁴12,932

W Withheld to avoid disclosing company proprietary data; included with "Other forms, shipments."

¹Crude sulfur or sulfur content.

²Includes Puerto Rico and the Virgin Islands.

³Includes consumption of hydrogen sulfide, liquid sulfur dioxide, and data indicated by symbol W.

⁴Data do not add to total shown because of independent rounding.

TABLE 11
ELEMENTAL SULFUR SOLD OR USED IN THE UNITED STATES, BY
END USE

(Thousand metric tons)

SIC	End use	1990	1991
20	Food and kindred products	W	W
26, 261	Pulp and paper products	30	24
282, 2822	Synthetic rubber and other plastic products	W	W
287	Agricultural chemicals	324	398
28, 286	Other chemical products and industrial organic chemicals	187	51
284	Soaps and detergents	W	W
29, 291	Petroleum refining and petroleum and coal products	104	147
281	Other industrial inorganic chemicals	126	14
	Sulfuric acid:		
	Domestic sulfur	7,870	6,746
	Imported sulfur	2,528	2,900
	Total	10,398	9,646
	Unidentified	538	605
	Total domestic uses	11,707	10,885
	Exports	952	939
	Grand total	12,659	11,824

W Withheld to avoid disclosing company proprietary data; included with "Unidentified."

TABLE 12
SULFURIC ACID SOLD OR USED IN THE UNITED STATES,
BY END USE

(Thousand metric tons of 100% H₂SO₄)

SIC	End use	1990	1991
102	Copper ores	1,955	2,103
1094	Uranium and vanadium ores	91	59
10	Other ores	273	209
261	Pulpmills	799	768
26	Other paper products	89	85
285, 2816	Inorganic pigments and paints and allied products	407	780
281	Other inorganic chemicals	1,589	542
282, 2822	Synthetic rubber and other plastic materials and synthetics	836	832
2823	Cellulosic fibers, including rayon	238	208
283	Drugs	47	40
284	Soaps and detergents	285	180
286	Industrial organic chemicals	763	942
2873	Nitrogenous fertilizers	421	668
2874	Phosphatic fertilizers	26,504	25,424
2879	Pesticides	102	28
287	Other agricultural chemicals	79	123
2892	Explosives	44	40
2899	Water-treating compounds	359	622
28	Other chemical products	168	493
29, 291	Petroleum refining and other petroleum and coal products	1,222	1,171
30	Rubber and miscellaneous plastic products	4	—
331	Steel pickling	113	101
333	Nonferrous metals	39	47
33	Other primary metals	6	4
3691	Storage batteries (acid)	143	109
	Unidentified	1,916	2,081
	Total domestic	38,492	37,659
	Exports	54	191
	Grand total	38,546	37,850

TABLE 13
SULFUR AND SULFURIC ACID SOLD OR USED IN THE UNITED STATES, BY END USE

(Thousand metric tons, sulfur content)

SIC	End use	Elemental sulfur ¹		Sulfuric acid (sulfur equivalent)		Total	
		1990	1991	1990	1991	1990	1991
102	Copper ores	—	—	639	688	639	688
1094	Uranium and vanadium ores	—	—	30	19	30	19
10	Other ores	—	—	89	68	89	68
20	Food and kindred products	W	W	—	—	W	W
26, 261	Pulpmills and paper products	30	24	290	279	320	303
28, 285, 286, 2816	Inorganic pigments, paints and allied products, industrial organic chemicals, other chemical products	² 187	² 56	133	255	320	311
281	Other inorganic chemicals	126	124	520	177	646	301
282, 2822	Synthetic rubber and other plastic materials and synthetics	W	W	273	272	273	272
2823	Cellulosic fibers, including rayon	—	—	78	69	78	69
283	Drugs	—	—	15	13	15	13
284	Soaps and detergents	W	W	93	59	93	59
286	Industrial organic chemicals	—	—	249	308	249	308
2873	Nitrogenous fertilizers	—	—	138	218	138	218
2874	Phosphatic fertilizers	—	—	8,664	8,311	8,664	8,311
2879	Pesticides	—	—	34	9	34	9
287	Other agricultural chemicals	324	398	26	40	350	438
2892	Explosives	—	—	14	13	14	13
2899	Water-treating compounds	—	—	117	203	117	203
28	Other chemical products	—	25	55	161	55	186
29, 291	Petroleum refining and other petroleum and coal products	104	147	400	383	504	530
30	Rubber and miscellaneous plastic products	—	—	1	—	1	—
331	Steel pickling	—	—	37	33	37	33
333	Nonferrous metals	—	—	13	15	13	15
33	Other primary metals	—	—	2	1	2	1
3691	Storage batteries (acid)	—	—	47	36	47	36
	Exported sulfuric acid	—	—	17	62	17	62
	Total identified	771	774	11,974	11,692	12,745	12,466
	Unidentified	538	605	626	680	1,164	1,285
	Grand total	1,309	1,379	12,600	12,372	13,909	13,751

W Withheld to avoid disclosing company proprietary data; included with "Unidentified."

¹Does not include elemental sulfur used for production of sulfuric acid.

²No elemental sulfur was used in inorganic pigments and paints and allied products.

TABLE 14
SULFURIC ACID FROM SMELTERS SOLD OR USED IN THE UNITED STATES, BY END USE

(Thousand metric tons of 100% H₂SO₄)

SIC	Use	1990	1991
102	Copper ores	1,882	1,917
1094	Uranium and vanadium ores	73	17
10	Other ores	107	68
26, 261	Pulp mills and other paper products	124	129
2816	Inorganic pigments	W	W
281	Other inorganic chemicals	171	89
2823	Cellulosic fibers	W	W
283	Drugs	W	W
2873	Nitrogenous fertilizers	W	W
2874	Phosphatic fertilizers	689	625
287	Other agricultural chemicals	37	79
2899	Water-treating compounds	183	209
28	Other chemical products	20	24
291	Petroleum refining	9	25
331	Steel pickling	W	W
333	Nonferrous metals	28	16
3691	Storage batteries (acid)	28	29
	Unidentified	1,117	661
	Total domestic	4,468	3,888
	Exports	W	W
	Grand total	4,468	3,888

W Withheld to avoid disclosing company proprietary data; included with "Unidentified."

TABLE 15
YEAREND SULFUR STOCKS OF U.S. PRODUCERS

(Thousand metric tons)

Year	Frasch	Recovered	Total ¹
1987	2,122	194	2,316
1988	954	158	1,112
1989	1,109	193	1,301
1990	1,177	245	1,423
1991	979	216	1,194

¹Data may not add to totals shown because of independent rounding.

TABLE 16
REPORTED SALES VALUES OF SHIPMENTS OF SULFUR, F.O.B. MINE OR PLANT

(Dollars per metric ton)

Year	Frasch	Recovered	Average
1987	107.15	79.63	89.78
1988	99.24	77.03	85.95
1989	100.18	78.70	86.62
1990	91.17	73.89	80.14
1991	87.05	64.17	71.45

TABLE 17
U.S. EXPORTS¹ OF ELEMENTAL SULFUR, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1990		1991	
	Quantity	Value	Quantity	Value
Australia	9	1,521	1	1,253
Belgium-Luxembourg	181	21,132	150	18,527
Brazil	201	26,869	142	14,216
Canada	22	3,763	10	2,420
China	8	702	5	411
Colombia	19	1,817	9	972
Denmark	(²)	39	—	—
France	32	2,692	50	6,505
Greece	19	3,105	—	—
India	150	14,311	149	12,715
Korea, Republic of	2	2,143	23	4,388
Mexico	232	19,502	178	15,984
Morocco	(²)	8	—	—
Senegal	12	1,095	67	7,034
South Africa, Republic of	(²)	85	11	1,040
Taiwan	25	2,987	7	1,331
Tunisia	20	1,841	112	11,328
Other	36	5,714	282	21,589
Total ³	972	109,327	1,196	119,713

¹Includes exports from the Virgin Islands.

²Less than 1/2 unit.

³Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 18
U.S. EXPORTS OF SULFURIC ACID (100% H₂SO₄), BY COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Australia	792	\$93	64	\$62
Canada	71,141	4,882	79,826	6,670
Chile	3,825	129	—	—
Dominican Republic	221	43	397	87
Ecuador	6,157	317	2,004	114
Israel	2,988	300	13,235	532
Jamaica	3,062	276	—	—
Korea, Republic of	5,546	1,877	1,920	774
Liberia	461	124	92	15
Mexico	11,815	650	14,169	814
Morocco	4,251	140	—	—
Netherlands	1,503	81	—	—
Netherlands Antilles	1,656	86	3,010	182
Panama	4,223	214	3,838	187
Saudi Arabia	6,856	273	1,483	126
Spain	83	3	7	8
Taiwan	1,142	278	2,558	476
Thailand	10,538	409	74	75
Trinidad and Tobago	594	20	816	49
United Kingdom	86	10	149	15
Venezuela	20,194	873	5,091	191
Other	4,375	437	20,139	1,428
Total	161,509	11,515	148,872	¹ 11,806

¹Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 19
U.S. IMPORTS OF ELEMENTAL SULFUR,
BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1990		1991	
	Quantity	Value ¹	Quantity	Value ¹
Canada	1,424	\$87,278	1,670	\$103,647
Mexico	1,129	116,789	1,259	130,840
Other ²	18	2,383	90	7,262
Total	2,571	206,450	³ 3,020	241,749

¹Declared customs valuation.

²Includes the Federal Republic of Germany, Japan, the Netherlands, and Venezuela in 1990; and Congo, the Dominican Republic, France, the Federal Republic of Germany, Japan, Monaco, the Netherlands, and United Kingdom in 1991.

³Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 20
U.S. IMPORTS OF SULFURIC ACID (100% H₂SO₄),
BY COUNTRY

Country	1990		1991	
	Quantity (metric tons)	Value ¹ (thou- sands)	Quantity (metric tons)	Value ¹ (thou- sands)
Argentina	3,638	\$36	4,175	\$54
Australia	—	—	38,756	137
Algeria	—	—	7,518	271
Canada	1,280,313	46,076	1,276,767	46,869
France	—	—	10,484	210
Germany, Federal Republic of	74,835	3,048	185,077	3,392
Ireland	—	—	—	—
Italy	24,801	1,323	21,957	441
Japan	36,251	1,356	76,977	814
Mexico	151,273	5,924	146,741	3,348
Netherlands	21,563	944	5,916	20
Norway	10,560	439	10,007	637
Poland	3,728	147	—	—
Spain	41,527	1,649	10,987	115
Sweden	31,354	1,225	152	4
Taiwan	6	5	—	—
United Kingdom	9,069	346	49,585	1,394
Other	700	64	126	20
Total²	1,689,618	62,581	1,845,225	57,727

¹Declared c.i.f. valuation.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 21
WORLD SULFUR ANNUAL
PRODUCTION CAPACITY,
DECEMBER 31, 1991, RATED
CAPACITY, SULFUR IN ALL
FORMS¹

(Thousand metric tons, sulfur content)

	Capacity
North America:	
Canada	8,400
United States	11,170
Total	19,570
Latin America:	
Brazil	500
Chile	440
Mexico	2,775
Other	675
Total	4,390
Europe:	
Belgium	400
Finland	620
France	1,850
Germany	2,530
Italy	830
Netherlands	350
Poland	4,900
Spain	1,550
Sweden	544
Turkey	613
U.S.S.R.	11,000
United Kingdom	500
Yugoslavia	750
Other	1,724
Total	28,161
Africa:	
South Africa, Republic of	1,000
Other	270
Total	1,270
Asia:	
China*	5,450
Iran	500
Iraq	1,600
Japan	4,100
Kuwait	330
Saudi Arabia	1,780
Other	1,400
Total	15,160
Oceania	330
World total	68,881

*Estimated.

¹Includes capacity at operating plants as well as plants on standby basis.

TABLE 22
SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE¹

(Thousand metric tons)

Country ² and source ³	1987	1988	1989	1990	1991 [*]
Algeria: Byproduct, natural gas and petroleum [*]	20	20	20	20	20
Australia: [*]					
Byproduct:					
Metallurgy	194	200	200	200	200
Petroleum	9	9	10	10	10
Total	203	209	210	210	210
Austria:					
Byproduct:					
Metallurgy	10	11	12	12	12
Natural gas and petroleum	25	36	37	30	27
Gypsum	13	—	—	—	—
Total	48	48	49	42	39
Bahrain: Byproduct, petroleum	48	48	48	48	48
Belgium: Byproduct, all sources [*]	300	310	320	310	300
Bolivia: Native	9	7	8	2	3
Brazil:					
Frasch	6	6	6	6	6
Pyrites	77	103	72	46	50
Byproduct:					
Metallurgy	153	152	164	166	166
Petroleum	77	61	60	58	60
Total	313	322	302	276	282
Bulgaria: [*]					
Pyrites	80	70	70	70	70
Byproduct, all sources	65	60	60	60	60
Total	145	130	130	130	130
Canada:					
Byproduct:					
Metallurgy	851	856	809	929	935
Natural gas	5,268	5,415	5,183	5,210	5,400
Petroleum [*]	142	152	149	207	265
Tar sands	426	485	491	503	500
Total [*]	6,687	6,908	6,632	6,849	7,100
Chile:					
Native:					
Refined	15	17	15	28	20
From caliche	22	21	1	([†])	([†])
Byproduct, metallurgy	335	416	400	400	400
Total	372	454	416	428	420
China: [*]					
Native	300	300	300	320	320
Pyrites	3,700	3,900	4,270	4,400	4,500
Byproduct, all sources	500	550	600	650	650
Total	4,500	4,750	5,170	5,370	5,470

See footnotes at end of table.

TABLE 22—Continued
SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE¹

(Thousand metric tons)

Country ² and source ³	1987	1988	1989	1990	1991*
Colombia:					
Native	41	43	46	'32	35
Byproduct, petroleum*	10	'8	8	8	8
Total*	'52	'51	54	'40	43
Cuba: Byproduct, petroleum*	5	5	5	5	4
Cyprus:⁶ Pyrites	41	51	26	—	—
Czechoslovakia:⁶					
Native	6	6	6	6	6
Pyrites	'38	60	50	50	50
Byproduct, all sources	40	40	40	40	40
Total	'84	106	96	96	96
Denmark: Byproduct, petroleum	13	14	'14	'12	12
Ecuador:⁶					
Native	5	5	4	4	4
Byproduct:					
Natural gas	5	5	5	5	5
Petroleum	5	5	5	5	5
Total	15	15	14	14	14
Egypt: Byproduct, natural gas and petroleum*	8	8	8	8	8
Finland:					
Pyrites	'317	'313	'306	'357	369
Byproduct:					
Metallurgy*	230	240	'180	'237	227
Petroleum	'52	47	41	'42	40
Total*	'599	'600	'527	'636	636
France:					
Byproduct:					
Natural gas	883	775	647	'666	794
Petroleum*	200	226	239	'233	225
Unspecified*	180	180	150	'150	180
Total*	1,263	1,181	1,036	'1,049	1,199
Germany, Federal Republic of					
Byproduct:					
Eastern states, all sources*	315	315	290	'260	190
Western states:					
Metallurgy* ⁷	300	310	315	320	300
Natural gas	1,029	952	'1,050	'858	900
Petroleum*	210	205	210	'280	300
Unspecified*	285	280	310	300	300
Total*	2,139	2,062	2,175	'2,018	1,990
Greece:⁶					
Pyrites	'65	'60	'45	'45	40
Byproduct:					
Natural gas	135	'185	'185	'185	195
Petroleum	5	5	5	5	5
Total	'205	'250	'235	'235	240

See footnotes at end of table.

TABLE 22—Continued
SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE¹

(Thousand metric tons)

Country ² and source ³	1987	1988	1989	1990	1991*
Hungary: ^o					
Pyrites	1	1	1	1	1
Byproduct, all sources	10	10	10	10	9
Total	11	11	11	11	10
India:					
Pyrites	'36	'30	'39	'35	35
Byproduct: ^o					
Metallurgy	120	125	125	125	125
Petroleum	'8	'10	5	'10	10
Total*	'164	'165	'168	'170	170
Indonesia: ^o Native	4	4	4	4	4
Iran: ^o					
Native	'—	'—	'—	'—	—
Byproduct:					
Metallurgy	20	25	40	45	50
Natural gas and petroleum	'240	'206	'460	'635	650
Total	'260	'231	'500	'680	700
Iraq: ^o					
Frasch	707	'958	'960	800	400
Byproduct, natural gas and petroleum	250	'427	370	250	30
Total	'957	'1,185	'1,330	1,050	430
Israel: Byproduct, natural gas and petroleum	40	68	68	'64	64
Italy: ^o					
Pyrites	'314	'4308	'323	'290	285
Byproduct, petroleum	'250	'310	'315	'297	315
Total	'564	'618	'638	'587	600
Japan:					
Pyrites	79	71	62	53	54
Byproduct:					
Metallurgy	1,250	1,268	'1,320	'1,336	1,400
Petroleum	1,020	1,093	1,176	'1,268	1,300
Total	2,349	2,432	'2,559	'2,657	2,754
Korea, North: ^o					
Pyrites	200	200	200	200	210
Byproduct, metallurgy	30	30	30	30	30
Total	230	230	230	230	240
Korea, Republic of: ^o					
Byproduct:					
Metallurgy	55	55	55	55	55
Petroleum	35	35	36	36	37
Total	90	90	91	91	92
Kuwait: Byproduct, natural gas and petroleum*	310	360	'475	'300	30
Libya: Byproduct, natural gas and petroleum*	14	14	15	15	15
Mexico:					
Frasch	1,806	1,628	1,528	'1,441	1,100

See footnotes at end of table.

TABLE 22—Continued
SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE¹

(Thousand metric tons)

Country ² and source ³	1987	1988	1989	1990	1991 ⁴
Mexico—Continued:					
Byproduct:					
Metallurgy [*]	154	240	286	290	280
Natural gas and petroleum	501	510	555	701	600
Total[*]	2,461	2,378	2,369	2,432	1,980
Namibia: Pyrites [*]	60	115	100	100	100
Netherlands: Byproduct, petroleum [*]	211	215	260	285	290
Netherlands Antilles: Byproduct, petroleum [*]	60	60	60	60	60
New Zealand: Byproduct, all sources	2	4	1	3	3
Norway:					
Pyrites	179	152	122	125	121
Byproduct:[*]					
Metallurgy	80	80	75	75	75
Petroleum	15	10	13	15	15
Total[*]	274	242	210	215	211
Oman:[*]					
Byproduct:					
Metallurgy	30	30	32	31	30
Natural gas and petroleum	17	17	25	35	40
Total	47	47	57	66	70
Pakistan:					
Native	1	1	—	(⁵)	(⁶)
Byproduct, all sources [*]	26	25	25	25	26
Total[*]	27	26	25	25	26
Peru:[*]					
Native	(⁷)	(⁸)	(⁹)	(¹⁰)	(¹¹)
Byproduct, all sources	66	66	66	66	66
Total	66	66	66	66	66
Philippines:					
Pyrites	158	160	195	134	150
Byproduct, metallurgy [*]	140	150	185	185	150
Total[*]	298	310	380	319	300
Poland:⁸					
Frasch	4,410	4,411	4,276	4,027	4,100
Native	550	589	588	637	550
Byproduct:[*]					
Metallurgy	170	150	150	140	140
Petroleum	35	30	20	20	20
Gypsum [*]	22	20	20	10	10
Total[*]	5,187	5,200	5,054	4,834	4,820
Portugal:					
Pyrites	123	110	91	95	96
Byproduct, all sources [*]	5	5	3	3	4
Total[*]	128	115	94	98	100
Qatar: Byproduct, natural gas [*]	53	54	52	52	52

See footnotes at end of table.

TABLE 22—Continued
SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE¹

(Thousand metric tons)

Country ² and source ³	1987	1988	1989	1990	1991 [*]
Romania:[*]					
Pyrites	340	370	439	300	300
Byproduct, all sources	350	380	375	350	350
Total	690	750	734	650	650
Saudi Arabia: Byproduct, natural gas and petroleum	1,432	1,378	1,423	1,435	1,450
Singapore: Byproduct, petroleum[*]	50	50	55	60	65
South Africa, Republic of:					
Pyrites	545	507	461	452	293
Byproduct:					
Metallurgy [*]	105	111	100	111	104
Petroleum [*]	110	120	115	121	120
Total	760	738	676	683	517
Spain:					
Pyrites	960	1,057	938	748	800
Byproduct:[*]					
Coal (lignite) gasification	2	2	2	2	2
Metallurgy	225	110	110	100	100
Petroleum	8	8	8	8	8
Total[*]	1,195	1,177	1,058	858	910
Sweden:					
Pyrites	215	286	233	230	225
Byproduct:[*]					
Metallurgy	130	125	125	125	120
Petroleum	50	45	40	40	40
Total[*]	395	456	398	395	385
Switzerland: Byproduct, petroleum[*]	4	4	4	4	4
Syria: Byproduct, natural gas and petroleum[*]	40	40	40	30	29
Taiwan: Byproduct, all sources	89	86	76	96	100
Trinidad and Tobago: Byproduct, petroleum[*]	5	5	5	5	5
Turkey:					
Native	39	30	23	20	20
Pyrites	22	75	96	90	93
Byproduct:					
Petroleum	9	16	13	15	15
Unspecified [*]	11	5	49	55	75
Total[*]	81	126	181	179	203
U.S.S.R.:[*]					
Frasch	1,100	1,100	1,100	1,000	900
Native	2,400	2,400	2,350	2,000	1,800
Pyrites	2,150	2,150	2,150	1,900	1,700
Byproduct:					
Metallurgy	1,250	1,375	1,350	1,200	1,100
Natural gas	2,400	3,290	2,500	2,500	2,200
Petroleum	450	450	450	425	400
Total	9,750	10,765	9,900	9,025	8,100

See footnotes at end of table.

TABLE 22—Continued
SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE¹

(Thousand metric tons)

Country ² and source ³	1987	1988	1989	1990	1991 [*]
United Arab Emirates: Abu Dhabi:[*]					
Byproduct:					
Natural gas	97	100	70	'80	100
Petroleum	8	10	10	10	10
Total	105	110	80	'90	110
United Kingdom:					
Byproduct:					
Metallurgy	51	55	'60	'66	45
Petroleum	119	129	'118	'129	120
Total	170	184	'178	'195	165
United States:					
Frasch	3,202	3,174	3,888	3,726	2,869
Pyrites	W	W	W	W	W
Byproduct:					
Metallurgy	1,003	1,125	1,190	1,294	1,298
Natural gas	2,536	2,501	2,537	2,336	2,403
Petroleum	3,624	3,943	3,973	4,200	4,242
Unspecified	173	3	4	4	4
Total ¹⁰	10,539	10,746	11,592	11,560	10,816
Uruguay: Byproduct, petroleum [*]	2	2	2	2	2
Venezuela: Byproduct, natural gas and petroleum [*]	125	'125	125	125	125
Yugoslavia:					
Pyrites and pyrrhotite	258	252	'296	'222	200
Byproduct: [*]					
Metallurgy	175	170	'175	'175	160
Petroleum	3	3	'4	3	2
Total [*]	436	425	'475	'400	362
Zaire: Byproduct, metallurgy [*]	35	'32	'29	'20	16
Zambia:					
Pyrites	19	27	'25	'30	30
Byproduct, metallurgy [*]	'87	'81	'75	'71	70
Total [*]	'106	'108	'100	'101	100
Zimbabwe:[*]					
Pyrites	21	18	25	25	25
Byproduct, all sources	5	5	5	5	5
Total	26	23	30	30	30
Grand total¹⁰	'56,968	'59,117	'59,471	'58,154	55,592
Of which:					
Frasch	'11,230	'11,277	'11,757	'11,000	9,375
Native	'3,392	'3,422	'3,345	'3,052	2,761
Pyrites	'9,998	'10,446	'10,555	'9,999	9,796
Byproduct:					
Coal (lignite) gasification	2	2	2	2	2
Metallurgy	'7,183	'7,522	'7,593	'7,737	7,588
Natural gas	'12,407	13,277	'12,229	'11,892	12,049

See footnotes at end of table.

TABLE 22—Continued
SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE¹

(Thousand metric tons)

Country ² and source ³	1987	1988	1989	1990	1991 ⁴
Grand total—Continued:					
Of which—Continued:					
Byproduct—Continued:					
Natural gas and petroleum, undifferentiated	3,022	3,009	3,620	3,647	3,087
Petroleum	6,851	7,332	7,475	7,926	8,062
Tar sands	426	485	491	503	500
Unspecified sources	2,422	2,325	2,384	2,386	2,362
Gypsum	35	20	20	10	10

¹Estimated. ²Revised. ³W Withheld to avoid disclosing company proprietary data; included with "Byproduct: Unspecified sources."

⁴Table includes data available through June 8, 1992.

²In addition to the countries listed, a number of nations may produce limited quantities of either elemental sulfur or compounds (chiefly H₂S or SO₂) as a byproduct of petroleum, natural gas, and/or metallurgical operations, but output, if any, is not quantitatively reported, and no basis is available for the formulation of reliable estimates of output. Countries not listed in this table that may recover byproduct sulfur from oil refining include Albania, Bangladesh, Brunei, Burma, Costa Rica, Guatemala, Honduras, Jamaica, Malaysia, Nicaragua, Paraguay, and the Republic of Yemen. Albania and Burma may also produce byproduct sulfur from crude oil and natural gas extraction. No complete listing of other nations that may produce byproduct sulfur from metallurgical operations (including processing of coal for metallurgical use) can be compiled, but the total of such output is considered as small. Nations listed in the table that may have production from sources other than those listed are identified by individual footnotes.

³The term "source" reflects both the means of collecting sulfur and the type of raw material. Sources listed include the following: (1) Frasch recovery; (2) native, comprising all production of elemental sulfur by traditional mining methods (thereby excluding Frasch); (3) pyrites (whether or not the sulfur is recovered in the elemental form or as acid); (4) byproduct recovery, either as elemental sulfur or as sulfur compounds from coal gasification, metallurgical operations, including associated coal processing, crude oil and natural gas extraction, petroleum refining, tar sand cleaning, and processing of spent oxide from stack-gas scrubbers; and (5) recovery from the processing of mined gypsum. Recovery of sulfur in the form of sulfuric acid from artificial gypsum produced as a byproduct of phosphatic fertilizer production is excluded because to include it would result in double counting. It should be noted that production of Frasch sulfur, other native sulfur, pyrites-derived sulfur, mined gypsum-derived sulfur, byproduct sulfur from extraction of crude oil and natural gas, and recovery from tar sands are all credited to the country of origin of the extracted raw material; in contrast, byproduct recovery from metallurgical operations, petroleum refineries, and spent oxides are credited to the nation where the recovery takes place, which in some instances is not the original source country of the crude product from which the sulfur is extracted.

⁴Reported figure.

⁵Less than 1/2 unit.

⁶In addition, may produce limited quantities of byproduct sulfur from oil refining.

⁷Includes only the elemental sulfur equivalent of sulfuric acid produced as a byproduct from metallurgical furnaces; additional output may be included under "Byproduct: Unspecified sources."

⁸Official Polish sources report total Frasch and native mined elemental sulfur output annually, undifferentiated; this figure has been divided between Frasch and other native sulfur on the basis of information obtained from supplementary sources.

⁹Estimates for 1987-91 include byproduct production from synthetic fuels.

¹⁰Data may not add to totals shown because of independent rounding.

TABLE 23
U.S. SULFUR SUPPLY-DEMAND RELATIONS

(Thousand metric tons)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
WORLD PRODUCTION ^a											
United States	12,145	9,787	9,290	10,652	11,609	11,087	10,539	10,746	11,592	11,560	10,820
Rest of world	41,405	40,772	40,480	41,847	42,162	42,649	46,429	48,371	47,879	46,594	44,772
Total	53,550	50,559	49,770	52,499	53,771	53,736	56,968	59,117	59,471	58,154	55,592
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Production:											
Frasch mines	6,348	4,210	3,202	4,193	5,011	4,043	3,202	3,174	3,888	3,726	2,869
Recovered elemental:											
Natural gas processing	1,971	1,960	2,371	2,407	2,373	2,246	2,536	2,501	2,537	2,336	2,402
Petroleum refining	2,288	2,444	2,584	2,807	2,940	3,570	3,624	3,943	3,973	4,200	4,242
Other forms	1,538	1,173	1,133	1,245	1,285	1,228	1,176	1,128	1,194	1,298	1,306
Total all forms	12,145	9,787	9,290	10,652	11,609	11,087	10,539	10,746	11,592	11,560	10,820
Industry stocks, Jan. 1	3,056	3,546	4,218	3,223	2,419	2,799	2,748	2,316	1,112	1,301	1,423
Imports	2,522	1,905	1,695	2,557	2,104	1,347	1,599	1,996	2,260	2,571	3,020
Total U.S. supply	17,723	15,238	15,203	16,432	16,132	15,233	14,886	15,058	14,964	15,432	15,263
Distribution of U.S. supply:											
Industry stocks, Dec. 31	3,546	4,218	3,223	2,419	2,799	2,748	2,316	1,112	1,301	1,423	1,194
Exports	1,392	961	992	1,334	1,365	1,895	1,242	1,223	1,024	972	1,196
Demand	12,785	10,059	10,988	12,679	11,968	10,586	11,323	12,712	12,685	13,056	12,932
Apparent surplus(+), deficit(-) of supply ²	—	—	—	—	—	+4	+5	+11	-46	-19	-59
U.S. DEMAND PATTERN											
Agriculture:											
Phosphoric acid	7,748	6,415	7,113	8,621	7,872	6,973	7,556	8,404	8,642	8,664	8,311
Other	659	566	703	603	686	683	642	598	431	522	665
Total	8,407	6,981	7,816	9,224	8,558	7,656	8,198	9,002	9,073	9,186	8,976
Drugs and food products	19	15	35	27	56	65	32	27	28	18	15
Soaps, detergents, and water treatment	284	287	257	167	215	249	204	221	200	210	262
Plastics and synthetic products	301	347	479	457	314	338	352	458	501	421	400
Paper products	302	267	262	295	286	266	294	288	328	320	303
Paints	149	178	128	113	111	119	118	122	138	133	255
Metal mining and processing	626	448	319	510	442	376	426	567	723	773	791
Explosives	14	15	20	39	31	30	49	44	17	14	13
Petroleum refining	1,230	935	819	954	913	947	973	958	825	504	530
Iron and steel production	88	86	94	88	69	69	67	74	59	37	33
Storage batteries (acid)	57	53	58	58	67	50	41	51	46	47	36
Other	1,308	447	701	747	906	421	569	900	747	1,393	1,318
Total industrial demand	4,378	3,078	3,172	3,455	3,410	2,930	3,125	3,710	3,612	3,870	3,956
Total U.S. primary demand	12,785	10,059	10,988	12,679	11,968	10,586	11,323	12,712	12,685	13,056	12,932

^aRevised.

¹Sulfur in all forms.

²The difference between total U.S. distribution of supply and total U.S. supply.

FIGURE 1
TRENDS IN THE SULFUR INDUSTRY IN THE UNITED STATES

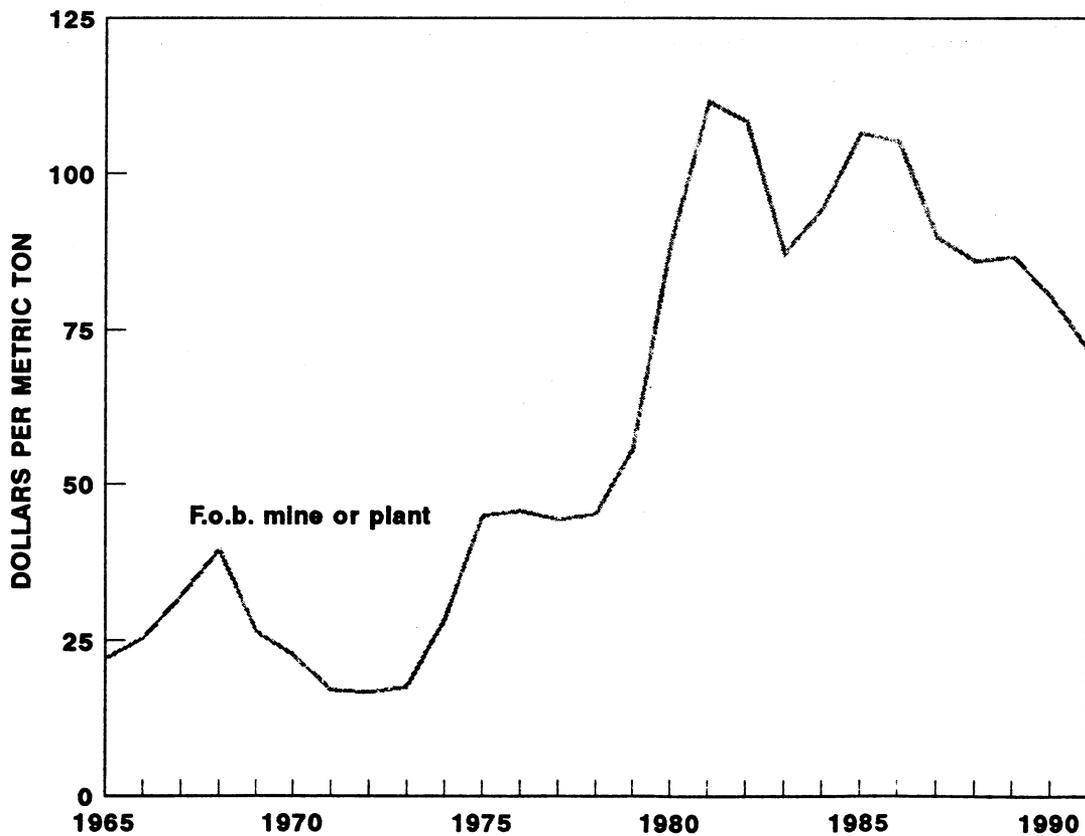
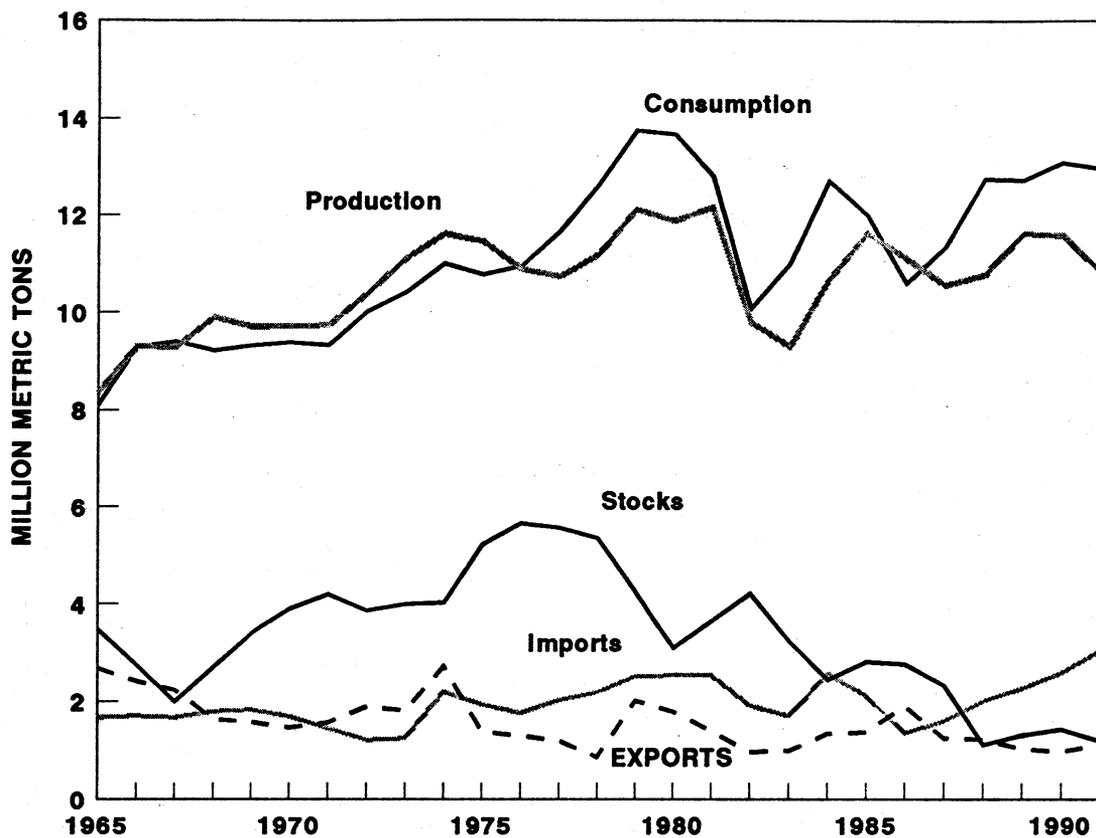


FIGURE 2
TRENDS IN THE PRODUCTION OF SULFUR IN THE UNITED STATES

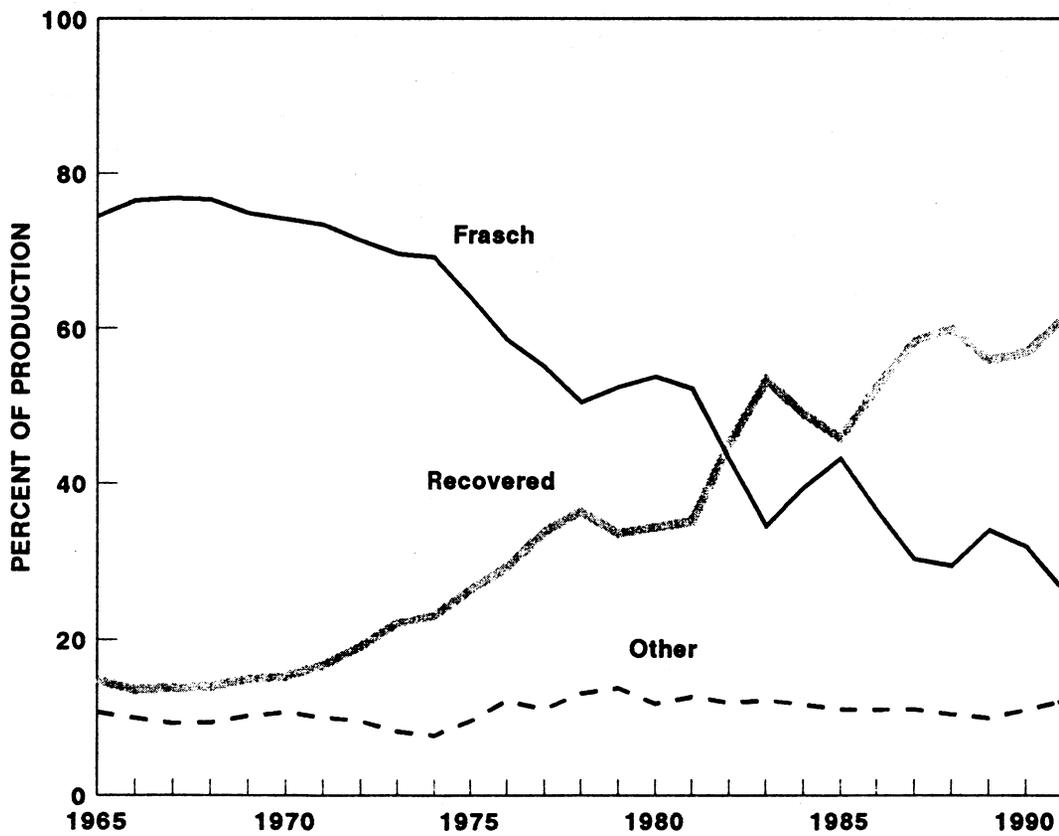
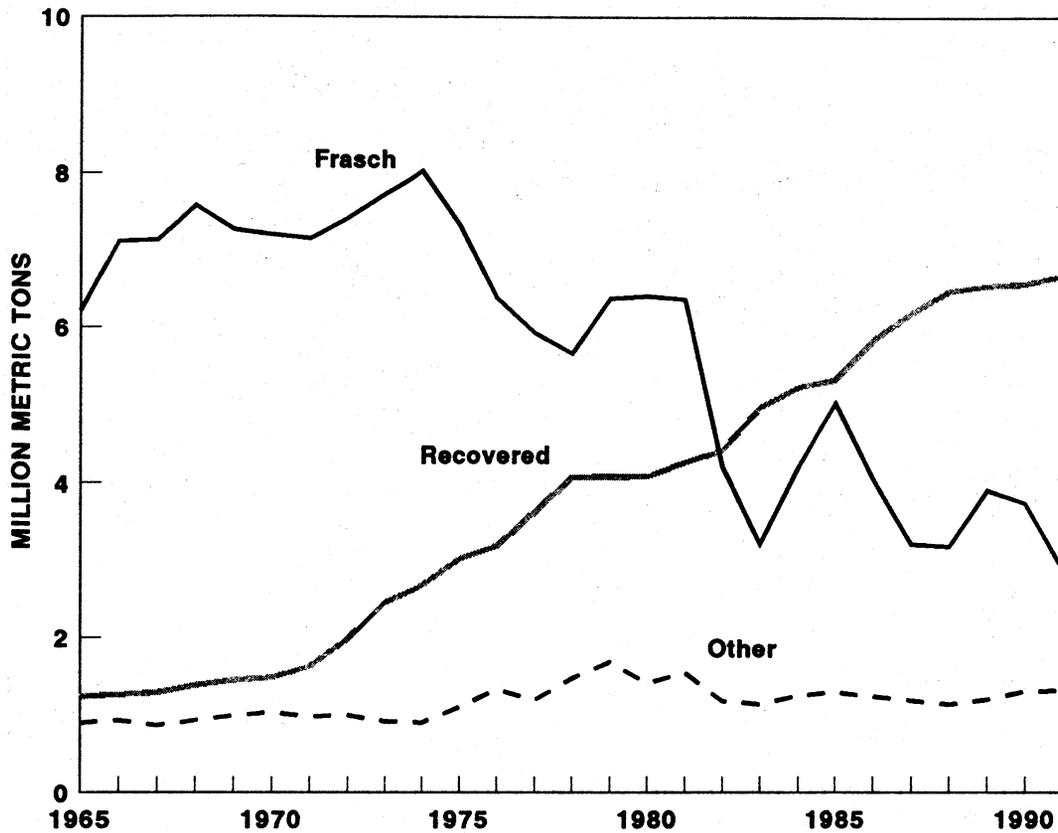


FIGURE 3
TRENDS IN THE CONSUMPTION OF SULFUR IN THE UNITED STATES

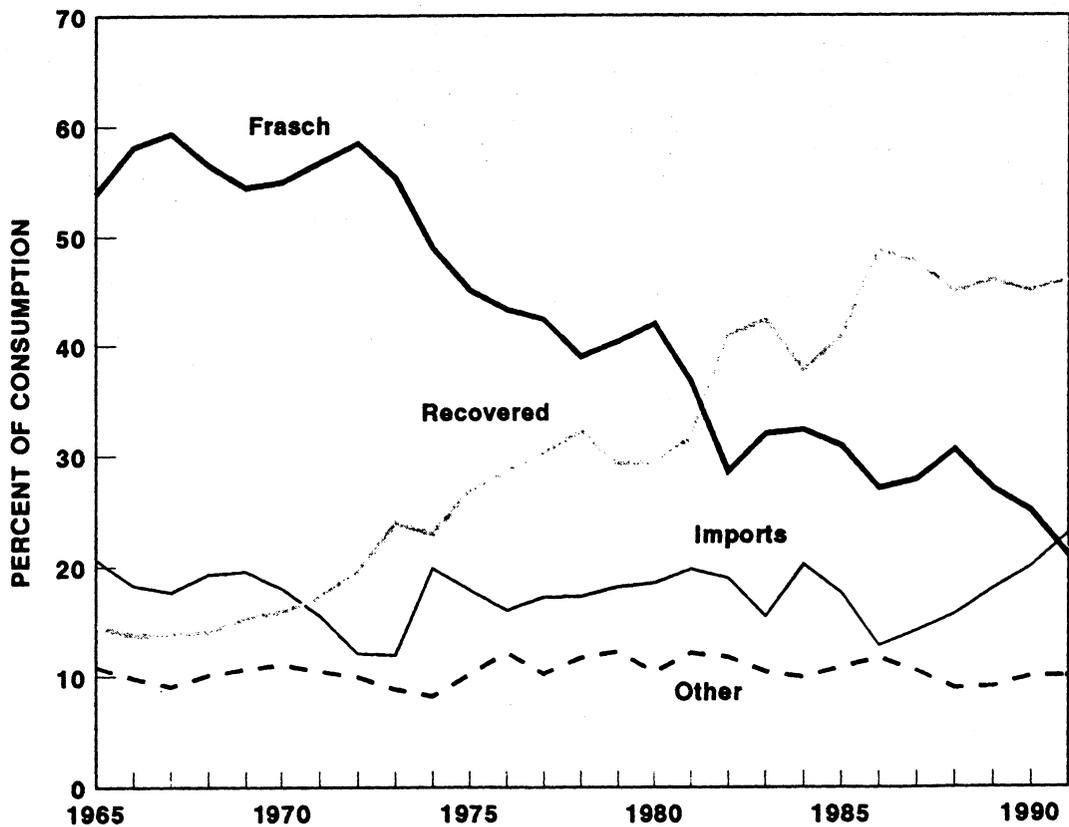
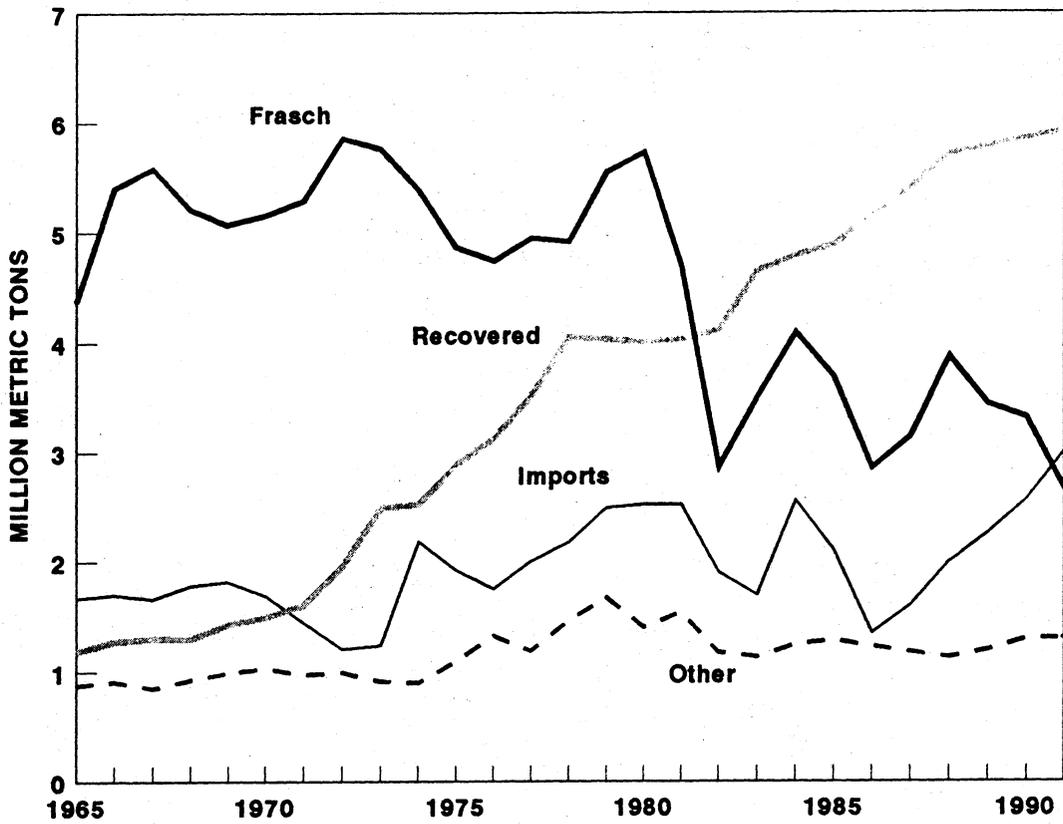
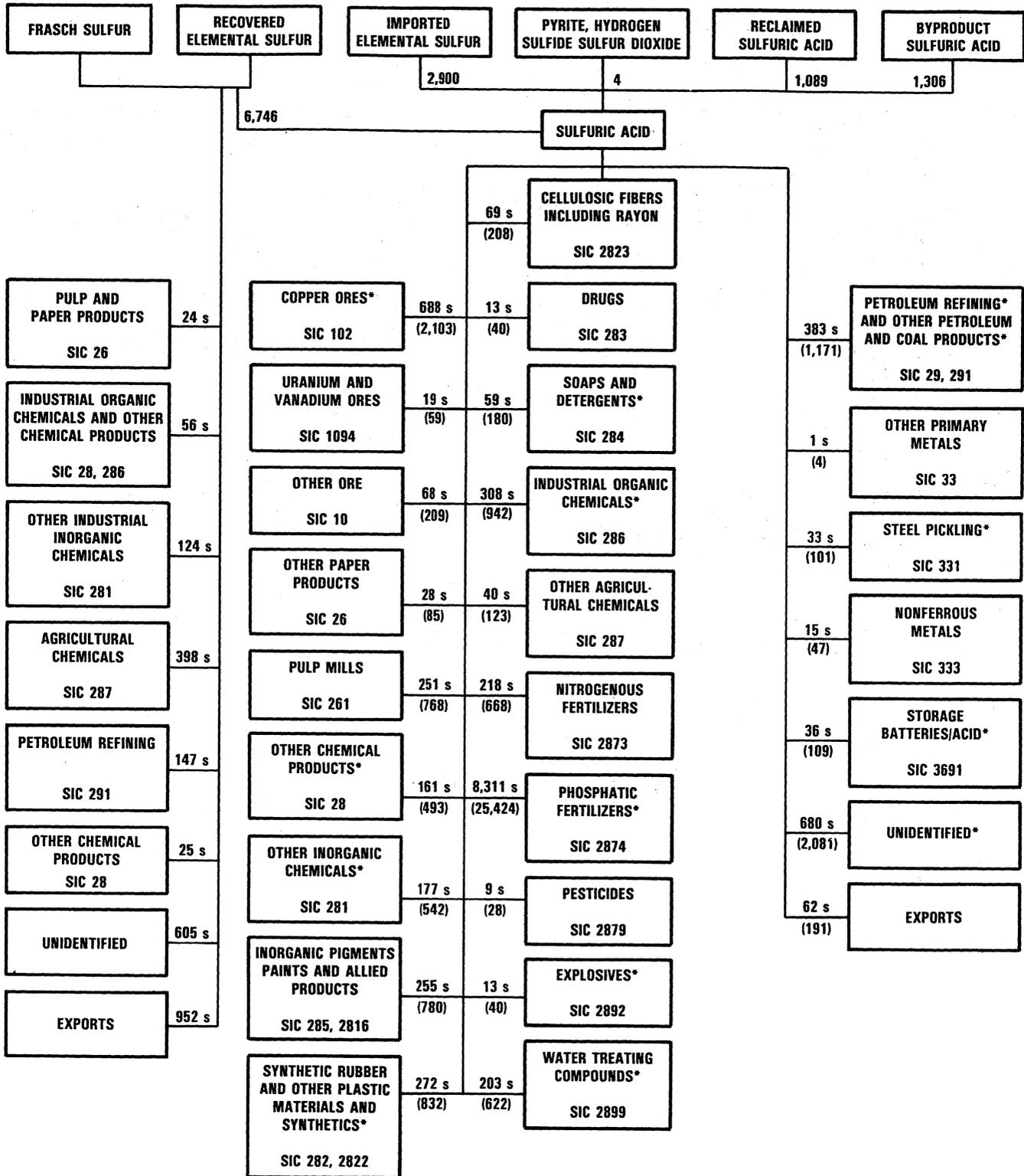


FIGURE 4
SULFUR-SULFURIC ACID SUPPLY AND END-USE RELATIONSHIP IN 1991



#s - SULFUR CONTENT THOUSAND METRIC TONS
 (#) - 100% SULFURIC ACID THOUSAND METRIC TONS
 * - SOURCES OF SPENT ACID FOR RECLAIMING

TALC AND PYROPHYLLITE

By Robert L. Virta

Mr. Virta, a physical scientist with 16 years U.S. Bureau of Mines experience, has been the commodity specialist for talc and pyrophyllite since 1986. Domestic survey data were prepared by Linder Roberts, statistical assistant; and international data tables were prepared by Brad Colquitt, international data assistant.

Domestic production of talc decreased 12% from that of 1990 to 1,040,000 metric tons and increased 3% in value to \$32 million. Sales of crude and processed talc decreased 15% in tonnage to 864,000 tons and 23% in value to \$83 million. Imports for consumption increased 3% in tonnage to 67,000 tons and 8% in value to \$12 million. Exports decreased 25% in tonnage to 178,000 tons and 9% in value to \$30 million. Over the past 10 years, talc production averaged 1,060,000 tons; sales, 957,000 tons; domestic consumption (talc and pyrophyllite), 955,000 tons; exports, 232,000 tons; and imports, 53,000 tons. The major use for talc was in ceramics, which accounted for 31% of the domestic consumption, followed by paint, 17%; paper, 16%; roofing, 11%; and plastics, 6%. Other applications accounted for 19% of consumption. Production and sales of pyrophyllite decreased from those of 1990. The major uses for pyrophyllite were in ceramics, refractories, insecticides, paint, plastics, and rubber.

DOMESTIC DATA COVERAGE

Domestic production and sales data for talc and pyrophyllite are developed by the U.S. Bureau of Mines from a voluntary survey of U.S. mines and mills. Survey forms were sent to 17 companies that operated 47 mines and mills. Sixteen companies that account for approximately 96% of the domestic production responded to the survey. Production data for the nonrespondent was estimated from reported prior-year production levels

adjusted by trends in employment and other guidelines. (See table 1.)

ANNUAL REVIEW

Legislation and Government Programs

The Occupational Safety Health Administration (OSHA) issued a final rule on June 8, 1992, removing the nonasbestiform varieties of actinolite, anthophyllite, and tremolite from the scope of its asbestos standard. The nonasbestiform varieties will be regulated according to limits set for "particulates not otherwise regulated."¹

The Mine Safety and Health Administration (MSHA) continued to review its proposed revisions to its air quality, chemical substances, and respiratory protection standards. The proposed permissible 8-hour time-weighted average exposure limit is 2.5 milligrams per cubic meter (mg/m^3) of air for talc (containing no asbestos), 3 mg/m^3 for respirable soapstone, and 6 mg/m^3 for total soapstone dust. The nonasbestiform varieties of tremolite, anthophyllite, and actinolite would be covered under the proposed respirable mine dust standard.²

MSHA continued reviewing its proposed rule that would create a hazard communication standard. Mine operators would be required to provide information to their employees through labeling, material safety data sheets, and employee training if hazardous chemicals were produced or used on the premises.

Issues

An issue that is attracting attention from some segments of the talc industry is the classification of crystalline silica as a probable human carcinogen by the International Agency for Research on Cancer, an agency of the World Health Organization. Additionally, OSHA-regulated sites that receive and/or use products containing more than 0.1% crystalline silica must comply with OSHA's Hazard Communication Standard (HCS). Both the classification of crystalline silica as a probable human carcinogen and the need to quantitatively analyze for crystalline silica at the 0.1% level to demonstrate exemption from the HCS are controversial.

Production

Talc.—Twelve companies operating 19 mines in 8 States produced talc, soapstone, and steatite. These companies generally were structured to cover all aspects of talc mining, from mining to processing. Only a few companies hired custom grinders to mill the ore. The largest of the domestic producers were Cyprus Minerals Co. Inc., Dal Minerals, Gouverneur Talc Co., Montana Talc Co., and Pfizer Inc. The major producing deposits were in Montana, New York, Texas, and Vermont.

Commercial talc production was from deposits that were formed through hydrothermal alteration of ultrabasic rocks and low-grade metamorphism of siliceous dolomites. They generally occur as lenses or pods in the country

rock. Magnesite, quartz, chlorite, magnetite, serpentine, anthophyllite, tremolite, dolomite, and actinolite may be present as accessory minerals.

Most of the domestic talc production was from open pit mining operations. Underground mining was used only when a large waste-rock-to-ore ratio made open pit mining uneconomical. Typically, overburden was removed and blasting was used to fracture the ore. The companies then used selective mining and manual or automated sorting to produce a high-grade feed for the mill. Jaw crushers were used to reduce the size of the mill feed, and ball mills or roller mills were used to produce the final product. Fluid-energy mills or pulverizing mills were used for ultrafine grinding of the talc ore. In a few instances, the ore was calcined prior to milling to increase its whiteness.

Flotation processes were used when the desired product purity was not obtained by using conventional processing. The milled ore was chemically treated, passed through rougher and cleaner cells to separate the talc from the gangue material, dried in a flash dryer, and ground in a pulverizer. Ore composition, reagent type, pulp density, pH of the flotation system, and residence time in the flotation circuits determined flotation efficiency.

Cyprus Minerals Co. signed a letter of intent to sell its talc operations to RTZ Corp. PLC, London. The sale includes talc operations in Alabama, California, Montana, Vermont, and Spain. Also included is a milling operation in Belgium and an interest in a talc operation in Japan.³

Southern Talc Co., a subsidiary of UCI, Louisville, KY, closed its mine in Georgia. The company recently built a flotation plant to improve the quality of its milled products but the ore could not be adequately upgraded for higher value markets.⁴

Pfizer Inc. completed its flotation mill at its Barretts, MT, operation. The \$8.6 million expansion will permit the company to produce a higher value talc product and extend the life of recoverable reserves.⁵

ECC Group PLC sold its U.S. subsidiary, Southern Clay Products Inc. Southern Clay Products' bentonite operations in Texas were sold to Laporte PLC.⁶ Its talc operations in Texas were sold to United Clays of Texas, a subsidiary of WBB Ltd., London.

U.S. mine production of crude talc decreased 12% in tonnage to 1,040,000 tons and increased 3% in value to \$32 million. Mines that operated in Montana, New York, Texas, and Vermont accounted for 96% of domestic talc production. Montana led all States in the tonnage and value of talc produced.

Pyrophyllite.—Pyrophyllite was mined by two companies operating three mines in North Carolina. Production was from hydrothermally altered volcanic deposits of acidic composition. The deposits consisted of pyrophyllite with sericite, andalusite, and/or quartz as accessory minerals. After removing the overburden, the ore was either stripped using dozers and scrapers or extracted using conventional open pit mining techniques. The ore was dried, and then jaw crushers and gyratory crushers were used to reduce the size of the mill feed. Ball, pebble, or roller mills were used to produce the final product.

U.S. mine production of crude pyrophyllite decreased in tonnage from that of 1990. (See table 2.)

Consumption and Uses

Talc.—Talc was used in a wide variety of products because of its softness (1 on the Mohs scale), purity, fragrance retention, whiteness, luster, moisture content, oil and grease adsorption, chemical inertness, low electrical conductivity, high dielectric strength, and high thermal conductivity. These properties were not universal to all talcose materials because of differences in their mineralogical composition and particle shape. Mineral content was extremely important because it determined the end use for the material. Generally, only two or three of these

properties were critical for any one application.

Domestic producers reported that overall sales (including exports by producers) declined 15% in tonnage to 864,000 tons and 23% in value to \$83 million in 1991. The major consumer of talc was the construction industry, with applications in ceramic tiles and sanitaryware, joint compounds, paint, and roofing. The end-use distribution was ceramics, 31%; paint, 17%; paper, 16%; roofing, 11%; plastics, 7%; cosmetics, 5%; and insecticides, refractories, rubber, and other, 14%. Reported sales to the ceramics and plastics industries increased in 1991. Sales to the paint, paper, and roofing industries declined as a result of the downturn in the building construction industry. More than 90% of the companies responded to the end-use portion of the 1991 annual survey, representing 91% of the data in table 3.

Pyrophyllite.—Pyrophyllite, being different in composition from talc, did not have the same applications as talc. Properties such as softness (1 to 2 on the Mohs scale), whiteness, chemical inertness, high melting point, low electrical conductivity, and high dielectric strength made pyrophyllitic materials useful for ceramics and refractories.

Domestic consumption of pyrophyllite decreased 3% in tonnage in 1991. The largest portion of domestically produced ground pyrophyllite was used in ceramics, followed by refractories, insecticides, paint, plastics, and rubber. (See table 3.)

Markets and Prices

Talc prices were based on the quality and on the degree and method of processing. The unit value of crude talc based on data reported by producers was \$32 per ton. The average reported unit value of processed talc was \$105 per ton. The average unit value of crude and processed pyrophyllite was unchanged from that of 1990. Unit values for imported crude and ground talc ranged from \$66 per ton to \$928 per ton for quantities greater than 100 tons. The

average unit value for all imported talc was \$178 per ton. Unit values for exported talc ranged from \$95 per ton to \$1,044 per ton for quantities greater than 100 tons and averaged \$169 per ton for all exports.

Prices, quoted by the American Paint & Coatings Journal, December 26, 1991, in U.S. dollars per metric ton for paint-grade talc in carload lots ranged from \$99 to \$226. Approximate equivalents, in dollars per metric ton, of price ranges quoted in Industrial Minerals (London), December 1991, for talc, c.i.f. main European ports, ranged from \$210 to \$385. (See table 4.)

Foreign Trade

Talc exports decreased 25% in tonnage to 178,000 tons and decreased 9% in value to \$30 million. Belgium-Luxembourg was the largest importer of talc, followed by Canada, Mexico, and Japan. Talc imports increased 3% in tonnage to 67,800 tons and 8% in value to \$12 million. Canada and China provided 86% of all talc imports. (See tables 5 and 6.)

World Review

China was the world's largest producer of talc. The United States remained the largest market economy talc producer, and Japan remained the largest pyrophyllite producer. China, Japan, and the United States accounted for 52% of the world's talc and pyrophyllite production.

Capacity.—The data in table 6 are annual rated capacity for mines and refineries as of December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought

into production within a short period of time with minimum capital expenditure. (See tables 7 and 8.)

Canada.—International Larder Minerals Inc. (ILM) evaluated a proposal to permit Bakertalc Inc. to mine ILM's undeveloped high-grade talc deposit near Thetford Mines, Quebec. The proposal also requested funding to upgrade Bakertalc's operations and reduce company debt.⁷

Finland.—Finnminerals operates three facilities in Finland. The flotation mill near Sotkamo is the largest of its operations. The facility produces approximately 180,000 tons of talc per year. The flotation process increases the purity of the talc to 97%. Talc is used by the paint, paper, and polymer industries. Its second facility, in northern Karelia, has an output of approximately 120,000 tons per year. Its third facility, in Luikonlahti, was acquired from the Partek Group in 1991. This operation produces approximately 75,000 tons per year for the fertilizer, paint, paper, and plastics industries.⁸

India.—Pyrophyllite is mined in Madhya Pradesh, Orissa, Rajasthan, Udaipur, and Uttar Pradesh. Approximately 46% of India's pyrophyllite production is from Madhya Pradesh. Talc is mined in Andhra Pradesh, Bihar, Madhya Pradesh, and Rajasthan. Production in Rajasthan accounts for 83% of India's talc production.⁹

Spain.—Three companies mine talc in Spain: Iberica de Talcos SA, Sdad Espanola de Talcos SA, and Distribuidora Malayuena de Talcos SA. Iberica de Talcos and Sdad Espanola de Talcos operate mines in the Pueblo de Lillo area. Sdad Espanola de Talcos produces 30,000 to 40,000 tons per year, one-half of which is cosmetic-grade talc. Distribuidora Malayuena, a subsidiary of Cyprus Minerals Co., operates mines near Mijas and Malaga. These facilities produce approximately 25,000 tons per

year for sale to the animal feed, chewing gum, fertilizer, olive oil, paint, paper, rubber industries.¹⁰

OUTLOOK

The average annual growth in domestic demand for talc and pyrophyllite was 1.2% between 1982 and 1991. Demand averaged between 900,000 and 1,000,000 tons per year for this period. Relative increases and decreases in demand have been the result of minor market fluctuations rather than long-term trends. Demand for talc and pyrophyllite is expected to continue to fluctuate about 1 million tons per year in the near future. With a slight improvement in the domestic economy predicted, talc markets affected by the current economic recession also should improve.

Ceramics will continue to be the major domestic end use for talc, followed by consumption in paint, paper, plastics, roofing, and cosmetics, in descending order. For pyrophyllite, the major domestic end uses will continue to be in ceramics and refractories.

⁷Federal Register. Occupational Safety and Health Administration. Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite. V. 57, No. 110, June 8, 1992, pp. 24310-24331.

⁸_____. Mine Safety and Health Administration. Air Quality, Chemical Substances, and Respiratory Protection Standards. V. 56, No. 39, Feb. 27, 1991, pp. 8168-8171.

⁹Cyprus Minerals Co. News. Cyprus Minerals Plans Sale of Talc Business to RTZ. Dec. 19, 1991, p. 1.

¹⁰Ellis, J. \$25 Million Talc Facility To Close. Chatsworth Times, Jan. 30, 1991.

¹¹Chemical Marketing Reporter. Pfizer Talc Starts, v. 239, No. 17, Apr. 29, 1991, p. 9.

¹²Wall Street Journal. U.S. Unit Agrees to Sell Southern Clay to Laporte, Aug. 10, 1991, p. A8.

¹³Industrial Minerals (London). Bakertalc/International Larder Deal. No. 283, Apr. 1991, p. 82.

¹⁴Russell, A. India's Industrial Minerals. Ind. Miner. (London), No. 288, Sept. 1991, pp. 45-55.

¹⁵Benbow, J. Finland's Mineral Industry. Ind. Miner. (London), No. 283, Apr. 1991, pp. 19-37.

¹⁶Industrial Minerals (London). Finnminerals Acquires Partek Talc. No. 280, Jan. 1991, p. 70.

¹⁷Griffiths, J. Spain's Minerals. Ind. Miner. (London), No. 285, June 1991, pp. 23-47.

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Other Sources

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Industrial Minerals, monthly.

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TABLE 1
SALIENT TALC AND PYROPHYLLITE STATISTICS

(Thousand metric tons and thousand dollars)

	1987	1988	1989	1990	1991
United States:					
Mine production, crude:					
Talc	1,080	1,136	1,172	1,185	1,037
Pyrophyllite	83	97	81	82	W
Total	1,163	¹ 1,234	1,253	1,267	1,037
Value:					
Talc	\$27,265	\$29,364	\$27,731	\$31,068	\$32,051
Pyrophyllite	\$1,607	\$1,820	W	W	W
Total	\$28,872	\$31,184	\$27,731	\$31,184	\$32,051
Sold by producers, crude and processed:					
Talc	975	940	1,065	1,021	864
Pyrophyllite	82	93	79	80	W
Total	1,057	1,033	¹ 1,145	1,101	864
Value:					
Talc	\$113,394	\$115,899	\$114,453	\$110,585	\$82,579
Pyrophyllite	\$3,712	\$4,164	W	W	W
Total	¹ \$117,107	\$120,063	\$114,453	\$110,585	\$82,579
Exports ² (talc)	255	260	319	238	178
Value	\$19,607	\$21,391	\$28,949	\$32,909	\$30,050
Imports for consumption (talc)	48	80	78	65	67
Value	\$10,348	\$12,268	\$12,128	\$11,056	\$11,925
Apparent consumption ³	956	1,054	1,012	1,054	926
World: Production	8,490	¹ 8,853	⁹ 9,359	⁹ 9,084	⁸ 8,932

¹Estimated. ²Revised. W Withheld to avoid disclosing company proprietary data; not included in total.

³Data may not add to totals shown because of independent rounding.

²Excludes powders—talcum (in package), face, and compact.

³Production, plus imports, minus exports, plus adjustments in Government and industry stock. Does not include imported pyrophyllite.

**TABLE 2
CRUDE TALC AND PYROPHYLLITE PRODUCED
IN THE UNITED STATES, BY STATE**

(Thousand metric tons and thousand dollars)

State	1990		1991	
	Quantity	Value	Quantity	Value
Montana (talc)	474	18,883	365	15,741
Texas (talc)	250	4,844	213	4,561
Oregon (talc)	(¹)	72	(¹)	68
Other ^{2 3}	543	7,270	459	11,682
Total^{3 4}	1,267	31,068	1,037	43,201

²Revised.

¹Less than 1/2 unit.

³Includes Alabama, Arkansas, California, Georgia (1990), North Carolina, Vermont, and Virginia.

⁴Does not include quantity and value for pyrophyllite.

⁵Data may not add to totals because of independent rounding.

**TABLE 3
END USES FOR GROUND TALC AND PYROPHYLLITE**

(Thousand metric tons)

Use	1990			1991		
	Talc	Pyrophyllite	Total	Talc	Pyrophyllite	Total
Ceramics	235	W	235	255	W	255
Cosmetics ¹	36	—	36	37	—	37
Insecticides	6	W	6	14	W	14
Paint	155	W	155	135	W	135
Paper	143	—	143	133	—	133
Plastics	48	W	48	53	W	53
Refractories	3	W	3	4	W	4
Roofing	94	—	94	88	—	88
Rubber	20	W	20	16	W	16
Other ²	109	W	109	77	W	77
Total³	849	4100	849	811	W	811

W Withheld to avoid disclosing company proprietary data.

¹Incomplete data. Some cosmetic talc known to be included in "Other."

²Includes art sculpture, asphalt filler and coatings, crayons, floor tile, foundry facings, rice polishing, stucco, and other uses not specified.

³Data may not add to totals shown because of independent rounding. Does not include pyrophyllite.

⁴Includes imported pyrophyllite.

**TABLE 4
PRICE OF TALC**

(U.S. dollars per metric tons)

	Value
Canada: Fine micron, Hegman No. 6	226
Montana: Ultrafine grind, Hegman No. 6	243
New York:	
Nonfibrous, bags, mill:	
98 % through 325 mesh	99
99.6 % through 325 mesh	115
Trace retained on 325 mesh	182
Norwegian:	
Ground (ex store)	245-263
Micronized (ex store)	289-385
French, fine-ground	210-333
Finnish, micronised	228-280
Italian, cosmetic-grade	306
Chinese, normal (ex store):	
UK 200 mesh	252
UK 325 mesh	271
New York, paint, minimum 20-ton lot	165

Sources: American Paint & Coatings Journal, Dec. 1991, Industrial Minerals (London), Dec. 1991.

**TABLE 5
U.S. EXPORTS OF TALC¹**

(Thousand metric tons and thousand dollars)

Year	Belgium-Luxembourg		Canada ²		Japan		Mexico		Other ³		Total ⁴	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1987	27	2,482	55	5,000	24	2,405	101	4,182	47	5,538	255	19,607
1988	27	3,942	62	5,079	30	3,849	97	3,225	44	5,296	260	21,391
1989	30	4,766	81	5,614	35	4,710	107	6,601	65	7,258	319	28,949
1990	45	6,109	43	6,995	31	4,233	*82	*8,006	37	7,566	238	32,909
1991	46	6,023	42	7,767	20	2,338	28	3,791	42	17,898	178	30,050

¹Estimated.

²Excludes powders-talcum (in package), face, and compact.

³Probably includes shipments in transit through Canadian ports.

⁴Includes 57 countries in 1991.

*Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 6
U.S. IMPORTS FOR CONSUMPTION OF TALC, BY COUNTRY

Country	Not crushed or powdered		Crushed or powdered		Cut and sawed		Total unmanufactured ¹	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989:	16,416	\$1,460	60,115	\$9,265	1,185	\$1,404	77,716	\$12,128
1990:								
Australia	5,449	554	7,014	373	—	—	12,463	927
Brazil	37	17	190	30	35	25	262	72
Canada	76	12	39,665	5,880	895	857	40,636	6,750
China	6,364	486	58	7	706	446	7,128	939
Italy	2,625	677	7	6	—	—	2,632	683
Korea, Republic of	—	—	527	122	—	—	527	122
Other ²	102	19	1,141	1,015	208	531	1,451	1,564
Total ¹	16,652	1,765	48,602	7,432	1,844	1,859	65,099	11,056
1991:								
Brazil	—	—	182	36	192	139	374	175
Canada	75	20	33,689	5,185	2,658	2,424	36,422	7,629
China	20,255	1,346	18	2	533	349	20,806	1,698
Italy	4,660	365	423	162	—	—	5,083	526
Korea, Republic of	—	—	546	116	—	—	546	116
Other ³	31	28	3,283	1,183	246	571	3,560	1,782
Total	25,061	1,758	38,141	6,683	3,629	3,484	66,791	11,925

¹Data may not add to totals shown because of independent rounding.

²Includes 24 countries.

³Includes 17 countries.

Source: Bureau of the Census.

TABLE 7
WORLD TALC AND
PYROPHYLLITE ANNUAL
PRODUCTION CAPACITY,
DECEMBER 31, 1991

(Thousand metric tons)

Country	Rated capacity ¹
North America:	
Canada	299
United States	1,361
Total	<u>1,660</u>
Latin America:	
Argentina	45
Brazil	454
Mexico	36
Other	36
Total	<u>571</u>
Europe:	
Austria	136
Finland	363
France	363
Italy	163
Norway	136
U.S.S.R.	544
Other	236
Total	<u>1,941</u>
Africa:	
Egypt	13
South Africa, Republic of	18
Other	1
Total	<u>32</u>
Asia:	
China	1,179
India	454
Iran	32
Japan	1,633
Korea, North	1
Korea, Republic of	998
Other	82
Total	<u>4,379</u>
Oceania:	
Australia	<u>227</u>
World total	<u>8,810</u>

¹Includes capacities of operating plants as well as plants on standby basis.

TABLE 8
TALC AND PYROPHYLLITE: WORLD PRODUCTION, BY COUNTRY AND PRODUCT¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991*
Argentina:					
Pyrophyllite	1,260	671	1,310	*1,300	1,200
Steatite*	300	250	250	250	250
Talc	27,103	26,108	26,658	*26,000	25,000
Australia:					
Pyrophyllite	6,036	5,750	*5,000	*5,000	6,000
Talc	206,865	199,631	*195,000	*200,000	210,000
Austria: Steatite	129,959	132,974	133,078	*133,971	133,000
Brazil:³					
Agalmatolite	104,536	122,531	*120,000	*120,000	120,000
Pyrophyllite	51,114	60,070	162,000	*120,000	120,000
Talc	425,513	378,463	433,000	*330,000	330,000
Burma: Steatite	22	*25	*20	*20	20
Canada (shipments): Pyrophyllite, soapstone, talc	136,418	*146,443	*144,828	*137,290	130,000
Chile: Talc	980	1,070	835	*898	900
China: Unspecified*	*1,700,000	*1,900,000	*2,100,000	*2,200,000	2,300,000
Colombia: Pyrophyllite, soapstone, talc	11,927	12,800	9,196	*10,113	10,000
Egypt: Pyrophyllite, talc, soapstone, steatite	*6,600	7,268	7,146	*6,340	6,000
Finland: Talc	*324,000	379,000	*398,000	*385,000	375,000
France: Talc	*328,800	*320,000	329,960	*284,000	300,000
Federal Republic of Germany, Western states: Talc (marketable)	19,785	19,500	13,000	*12,000	12,000
Greece: Steatite	1,507	*1,587	*1,600	*1,600	1,600
Hungary: Talc*	15,000	13,000	12,000	12,000	10,000
India:					
Pyrophyllite	51,724	64,923	97,264	*80,000	80,000
Steatite	359,448	417,493	414,268	*390,000	400,000
Iran: Talc⁴	*16,975	*29,261	*11,039	*31,087	30,000
Italy: Steatite and talc	150,718	158,722	146,000	*158,851	158,500
Japan:					
Pyrophyllite	1,241,069	1,244,491	1,233,600	*1,213,036	*1,229,287
Talc	55,899	49,797	55,665	61,550	*65,625
Korea, North: Unspecified*	170,000	170,000	170,000	170,000	170,000
Korea, Republic of:					
Pyrophyllite	690,819	673,776	770,298	*657,611	660,000
Talc	161,052	146,478	162,098	*181,600	180,000
Mexico: Talc	17,469	13,645	13,908	*13,590	*14,368
Nepal: Talc⁵	3,359	4,430	6,728	*1,798	2,000
Norway: Talc*	100,000	100,000	100,000	100,000	100,000
Pakistan: Pyrophyllite	23,278	37,429	38,290	*30,177	30,000
Paraguay: Unspecified	180	150	200	*200	200
Peru:					
Pyrophyllite	705	*9,200	*7,500	*7,500	7,500
Talc	1,447	*1,450	*1,500	*1,500	1,500
Philippines: Talc	—	27	—	—	—
Portugal: Talc	7,292	7,187	8,063	7,926	8,000

See footnotes at end of table.

TABLE 8—Continued
TALC AND PYROPHYLLITE: WORLD PRODUCTION, BY COUNTRY AND PRODUCT¹

(Metric tons)

Country ²	1987	1988	1989	1990	1991 ³
Romania: Talc ⁴	¹ 50,000	¹ 50,000	¹ 45,638	¹ 40,000	40,000
South Africa, Republic of:					
Pyrophyllite	3,467	3,162	3,942	2,759	⁴ 4,448
Talc	8,005	10,111	11,596	11,179	⁶ 6,235
Spain: Steatite	75,307	68,979	⁷ 75,000	⁷ 75,000	70,000
Sweden: Talc and steatite ⁵	¹ 16,981	16,000	16,000	16,000	16,000
Taiwan: Talc	22,102	21,603	22,559	² 22,123	22,000
Thailand:					
Pyrophyllite	37,749	37,285	39,799	² 29,290	30,000
Talc	4,101	4,843	7,242	⁴ 4,360	4,000
Turkey	¹ 15,000	5,397	5,614	⁶ 6,000	6,000
U.S.S.R.: Talc ⁶	530,000	530,000	530,000	500,000	450,000
United Kingdom: Talc	12,529	14,182	15,413	¹ 14,781	15,000
United States:					
Pyrophyllite	83,000	97,000	81,301	82,025	W
Talc	1,080,000	1,136,347	1,171,871	1,185,142	¹ 1,037,196
Uruguay: Talc ⁶	¹ 1,648	1,600	1,600	¹ 1,600	1,600
Zambia: Talc	258	73	114	¹ 160	180
Zimbabwe: Talc	516	976	1,513	¹ 1,787	1,500
Total	⁸8,489,822	⁸8,853,158	⁹9,358,504	⁹9,084,414	8,848,235
Of which:					
Pyrophyllite	2,190,221	² 2,233,757	² 2,440,304	² 2,228,698	2,168,435
Steatite	566,543	⁶ 621,308	⁶ 624,216	⁶ 600,841	604,870
Talc	³ 3,420,698	³ 3,458,782	³ 3,575,000	³ 3,430,081	3,242,104
Unspecified	² 2,297,360	² 2,533,914	² 2,713,370	² 2,818,794	2,910,700

¹Estimated. ²Revised.

³Table includes data available through May 11, 1992.

⁴In addition to the countries listed, Czechoslovakia produces talc, but information is inadequate to make reliable estimates of output levels.

⁵Total of beneficiated production, salable direct shipping production, and that consumed by producers.

⁶Data based on Iranian fiscal year beginning Mar. 21 of year stated.

⁷Reported figure.

⁸Data based on Nepalese fiscal year beginning mid-July of year stated.

THALLIUM

By Thomas O. Llewellyn

Mr. Llewellyn, a physical scientist with over 30 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for thallium since 1987. Domestic survey data were prepared by Carolyn F. Crews, statistical assistant.

In 1991, domestic demand for thallium metal was met by imports. Thallium is a trace element with an estimated average abundance of 2.2 parts per million in zinc sulfide ores and is a byproduct recovered from flue dust and residues collected in the smelting of zinc as well as copper and lead. There are a number of rare thallium minerals found in nature, which have no commercial importance as sources of thallium metal.

BACKGROUND

Current Research

A thallium-copper oxide superconductor, said to have a very high superconductivity transition temperature, was reportedly developed at the Superconductivity Research Laboratory, Tokyo, Japan.¹ Researchers in California designed a practical X-ray laser using energized atoms of thallium. The X-ray laser beam can penetrate living tissue like conventional X-rays, but it can also produce three-dimensional pictures of proteins as they react inside living cells.²

Operating Factors

Thallium metal and its compounds are highly toxic; they should be handled with extreme care and require the use of rubber gloves. It can be absorbed into the human body by skin contact, ingestion, or by inhaling dust or fumes. The element is not quickly eliminated from the body; therefore, absorption of subtoxic quantities eventually may accumulate to a toxic level.

ANNUAL REVIEW

Production

Although thallium was contained in ores mined or processed in the United States, it was not recovered domestically as a marketable product in 1991.

Consumption and Uses

Based on import data and discussions with metal traders, the domestic consumption of thallium in 1991 was estimated to be 850 kilograms, about 21% higher than that in 1990.

Thallium was used in superconductivity research, gamma radiation-detection equipment, additives for changing the refractive index and density of glass, low temperature mercury-thallium alloy switches, high-density liquids, alloys, photosensitive devices, and radioactive isotopes for cardiovascular diagnostic procedures.

Markets and Prices

Thallium metal was sold at various prices during the year according to its purity. Metal traders reported that the average price of thallium metal in 100-kilogram lots was \$190 per kilogram for 99.99%-pure thallium metal. The average value per kilogram of unwrought thallium metal and waste and scrap imported into the United States was estimated to be about \$181 per kilogram.

Foreign Trade

In 1991, thallium materials were imported from Belgium, Canada, and the United Kingdom. However, Belgium remained the principal source of imported thallium materials. Since January 1, 1990, the import duty for unwrought thallium and waste and scrap (Harmonized code 8112.91.6000) has been 5.5% ad valorem for most favored nations (MFN) and 25% ad valorem for non-MFN.

Thallium producers are granted a depletion allowance of 14% on both domestic and foreign production.

World Review

World production data for thallium were not available. The U.S. reserves in zinc ores were estimated to be about 32,000 kilograms. Rest-of-the-world reserves were estimated to be 345,000 kilograms of thallium.

OUTLOOK

The United States is not expected to resume recovery of thallium within the next 5 years. The toxicity of thallium is the factor that continues to influence domestic dependence on foreign sources for its supply.

¹American Metal Market. Thallium-Copper Oxide Superconductor Arrives. V. 99, No. 130, July 10, 1991, p. 4.

²Bishop, J. E. X-Ray Lasers' Chances Are Looking Brighter. Wall Street Journal. V. CCXVIII, No. 30, Feb. 12, 1991, p. B1.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Thallium. Ch. in Mineral Commodity Summaries, annual.

Thallium. Ch. in Minerals Facts and Problems, 1985 ed.

Other Sources

Chemical Marketing Reporter.
Metals Week.

TABLE 1

U.S. IMPORTS FOR CONSUMPTION OF THALLIUM, BY COUNTRY

	Gross weight (kilograms)	Value
1990:		
Belgium	450	61,482
1991:		
Belgium	886	131,104
Canada	27	38,150
United Kingdom	100	14,600
Total	1,013	183,854

Source: Bureau of the Census.

THORIUM

By James B. Hedrick

Mr. James B. Hedrick, a geologist and physical scientist with the Federal Government for 14 years, has been the commodity specialist for thorium since 1982. Domestic survey data were prepared by Kevin Bacon, statistical assistant; and the international data table was prepared by Harold Willis, international data assistant.

Domestic consumption of refined thorium products decreased, according to the U.S. Bureau of Mines, Department of the Interior. Thorium was recovered worldwide primarily from the rare-earth ore mineral monazite, a byproduct of processing heavy-mineral sands for titanium and zirconium minerals or tin minerals. Thorium compounds are produced from monazite during processing for the rare earths. Only a small portion of the thorium produced is consumed; most is discarded as waste. The major monazite-producing countries were Australia, Brazil, China, India, Malaysia, the Republic of South Africa, Sri Lanka, Thailand, and the United States. None of the domestically produced monazite was refined in the United States. Essentially all of the thorium compounds used by the domestic industry originated from either imports or U.S. Government stocks.

Limited demand for thorium, relative to the rare earths, continued to create an extensive world oversupply of thorium compounds and residues. Excess thorium, not designated for commercial use, was either disposed of as a radioactive waste or stored for potential use as a nuclear fuel or other application. Major nonenergy uses were in the traditional areas of refractories and lighting. Coleman Co. announced it had developed a suitable substitute for thorium used in incandescent lamp mantles.

Thorium's natural radioactivity represented a significant problem to those companies involved in its mining, processing, and use. Increased costs to comply with environmental regulations

and to pay for storage and waste disposal were the principal problems cited by industry, not health factors associated with its natural radioactivity.

DOMESTIC DATA COVERAGE

Domestic mine production data for thorium-bearing monazite are developed by the U.S. Bureau of Mines from a voluntary survey of U.S. operations entitled, "Rare Earths, Thorium, and Scandium." The one mine to which a survey form was sent responded, representing 100% of domestic production. Mine production data for thorium are withheld to avoid disclosing company proprietary data. Statistics on domestic thorium consumption are developed by surveying various processors and end users, evaluating import-export data, and analyzing Government stockpile shipments. (See table 1.)

ANNUAL REVIEW

Legislation and Government Programs

The calendar year 1991 included the U.S. Government fiscal years for 1991 and 1992. Public Law 101-189, the National Defense Authorization Act for Fiscal Years 1990 and 1991, covered the first 9 months of 1991 and continued the authorization for disposal of all stocks of thorium nitrate in excess of the National Defense Stockpile goal of 272,155 kilograms (600,000 pounds). Thorium nitrate classified as excess to goal at yearend 1991 was 2,946,185 kilograms (6,495,225 pounds). In the last 3 months

of 1991, Public Law 102-190, the National Defense Authorization Act for Fiscal Years 1992 and 1993, renewed the authorization to dispose of thorium nitrate at the aforementioned levels.

Legislation was proposed to revise the National Defense Stockpile goal for thorium nitrate to zero. Congressional action on the proposal was expected in 1992.

Production

RGC (USA) Minerals Inc., previously Associated Minerals (USA) Ltd. recovered thorium-bearing monazite for its rare-earth content at its dredging operation near Green Cove Springs, FL. Monazite was produced as a byproduct during processing for titanium and zirconium minerals. One rare-earth processor in Texas produced thorium as a byproduct compound. None of the monazite produced domestically was processed in the United States for its thorium content. Essentially all thorium alloys and compounds used by the domestic industry were derived from either imports, company stocks, or U.S. Government stocks. Domestic companies processed or fabricated various forms of thorium for nonenergy uses such as ceramics, incandescent lamp mantles, carbon arc lamps, magnesium-thorium alloys, refractories, magnetrons, triodes, crossfield amplifiers, and welding electrodes. The value of thorium compounds and alloys used by the domestic industry were estimated at \$1 million.

W.R. Grace and Co. announced it had switched from a thorium-bearing

monazite feed to a thorium-free rare-earth chloride feed for its rare-earth plant in Chattanooga, TN. The feed change to a thorium-free material was the result of increased disposal costs at approved radioactive waste sites. (See table 2.)

Consumption and Uses

Domestic thorium producers reported consumption of 54.3 metric tons of thorium oxide equivalent in 1991, a decrease of 11.2 metric tons from the 1990 level. Nonenergy uses accounted for all of the total consumption. The decrease in consumption was the result of decreased demand for thorium used in lamp mantles as Coleman Co. developed a proprietary thorium-free mantle coating using rare earths. The approximate distribution of thorium by end use, based on data supplied by producer, processors, and several consumers, was as follows: refractory applications, 85%; lamp mantles and lighting, 13%; metallurgical applications, 1%; and ceramics and welding electrodes, 1%.

Thorium oxide (thoria) has the highest melting point of all metal oxides, 3,300° C, a property that contributed to its use in several refractory applications. High-temperature uses were in high-temperature ceramics, investment molds, and crucibles.

Thorium nitrate was used in the manufacture of some mantles for incandescent "camping" lanterns, including natural gas lamps and oil lamps. Thorium mantles provide an intense white light that is adjusted toward the yellow region by a small addition of cerium. Its use in this application is declining due to the development of a suitable thorium-free substitute.

Thorium nitrate was also used to produce thoriated tungsten welding electrodes. Thoriated tungsten welding electrodes were used to join stainless steels, nickel alloys, and other alloys that require a continuous and stable arc to achieve precision welds.

The nitrate form was also used to produce thoriated tungsten elements used in the cathode (negative pole) of magnetron tubes. Thorium was used

because of its ability to emit electrons at relatively low temperatures when heated in a vacuum. Magnetron tubes were used to emit electrons at microwave frequencies to heat food in microwave ovens, in radio frequency (RF) induction heating, and in radar communication. Magnetrons were also used in military and commercial aircraft tracking radar and in weather radar.

Thorium was used in other types of electron emitting tubes, elements in special use light bulbs, high-refractivity glass, radiation detectors, computer memory components, catalysts, photoconductive films, target materials for X-ray tubes, and fuel cell elements.

Thorium fluoride was used in the manufacture of carbon arc lamps. Carbon arc lamps were used in searchlights, movie projectors, and cinematography lighting.

Most thorium used in metallurgical applications was alloyed with magnesium. Magnesium-thorium alloys used by the aerospace industry are lightweight, have high-strength, and have excellent creep resistance at elevated temperatures. Small quantities of thorium were used in dispersion hardened alloys for high-strength, high-temperature applications.

Thorium was used as a nuclear fuel in the thorium-232/uranium-233 fuel cycle. Only a few foreign-based nuclear reactors continued to operate with this fuel cycle.

Stocks

Government stocks of thorium nitrate in the National Defense Stockpile were 3,219,457 kilograms (7,097,687 pounds) on December 31, 1991. The stockpile's goal at yearend was 272,155 kilograms (600,000 pounds) of thorium nitrate. Stocks classified as excess to goal totaled 2,946,185 kilograms (6,495,225 pounds) and were all authorized for disposal.

The U.S. Department of Energy's inventory at yearend was 1,244,020 kilograms (2,742,595 pounds) of thorium oxide equivalent contained in ore, metal, and various compounds.

Prices

The price range of Australian monazite (minimum 55% rare-earth oxide, including thoria, f.o.b.),¹ as quoted in Australian dollars (A\$),² decreased from A\$800 to A\$900 per metric ton at yearend 1990 to A\$650 to A\$700 per metric ton at yearend 1991. Changes in the United States-Australia foreign exchange rate in 1991, resulting from a slighter weaker Australian dollar, caused the corresponding U.S. dollar to be up \$0.02 against the Australian dollar at yearend. The U.S. price range, converted from Australian dollars, decreased substantially from US\$618 to US\$695³ per metric ton in 1990 to US\$494 to US\$532⁴ per metric ton in 1991.

Thorium prices quoted by the Reed Manufacturing division of Magnesium Elektron, Flemington, NJ, at yearend 1991 were \$220.35 per kilogram (\$99.95 per pound) for thorium hardener (80%Mg-20%Th) in single drum quantities and \$41.40 per kilogram (\$18.78 per pound) for thorium-containing HZ-32 magnesium alloy ingot.

World Review

France.—Rhône-Poulenc SA was the leading producer of thorium compounds. Thorium was produced as a byproduct during processing for the rare earths at its operations in La Rochelle, France, and at Freeport, TX. It was derived almost entirely from the rare-earth ore mineral monazite.

United Kingdom.—The principal magnesium-thorium alloy producer in the United Kingdom, Magnesium Elektron has reportedly ceased production of magnesium-thorium alloys and master alloys. Sufficient stocks were produced to supply domestic needs for about 5 years. (See tables 3 and 4.)

OUTLOOK

Nonenergy uses of thorium are expected to continue to decrease. The long-term outlook for demand is for a significant decline. Industry users have

been successful in developing suitable substitutes for thorium used in incandescent lamp mantles and ceramic applications. The search for substitutes is expected to last as long as the costs of environmental compliance continues to escalate. Costs associated with handling, storing, and disposing of thorium have continued to increase. In addition, public concerns and potential liabilities arising from its natural radioactivity are expected to continue to impact thorium's use. No shortage of thorium is anticipated.

¹Free on board.

²Metal Bulletin (London). Non-ferrous Ores in Europe. No. 7644, Dec. 30, 1991, p. 24.

³Values have been converted from Australian dollars (A\$) to U.S. dollars (US\$) at the exchange rate of A\$1.2945=US\$1.00 based on yearend 1990 foreign exchange rates reported in the Wall Street Journal.

⁴Values have been converted from Australian dollars (A\$) to U.S. dollars (US\$) at the exchange rate of A\$1.3158=US\$1.00 based on yearend 1991 foreign exchange rates reported in the Wall Street Journal.

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Bureau of Mines Information Circulars.

Bureau of Mines Minerals Yearbook.

Bureau of Mines Mineral Facts and Problems.

TABLE 1
SALIENT U.S. REFINED THORIUM STATISTICS

(Metric tons of ThO₂, unless otherwise specified)

	1987	1988	1989	1990	1991
Exports:¹					
Metal, waste and scrap	20.41	2.74	NA	NA	NA
Compounds ²	NA	NA	8.25	0.22	2.65
Imports:¹					
Thorium ore metal, excluding monazite ²	NA	NA	250.38	188.62	205.10
Compounds	30.69	13.23	33.34	18.60	42.60
Shipments from Government stockpile excesses	—	3.06	—	2.17	—
Consumption, reported nonenergy applications ³	39.41	63.63	57.20	65.51	54.28
Prices, yearend, dollars per kilogram, ThO₂:⁴					
Nitrate, mantle-grade	\$10.10	\$13.80	(⁵)	\$16.55	\$19.94
Oxide, 99%-grade	\$41.00	\$45.00	(⁵)	\$55.00	\$63.80

NA Not available.

¹Because of the implementation of the Harmonized Tariff System begun in Jan. 1989, import and export categories for 1989 and later are not necessarily comparable to those of previous years.

²Data not available prior to Jan. 1989.

³All domestically consumed thorium was derived from imported metals, alloys, and compounds; monazite containing thorium has been imported annually but has not recently been used to produce thorium products.

⁴Source: Rhône-Poulenc Basic Chemicals Co.

⁵Data withheld by company.

TABLE 2
U.S. COMPANIES WITH THORIUM PROCESSING
AND FABRICATING CAPACITY

Company	Plant location	Operations and products
Atomergic Chemetals Corp.	Plainview, NY	Produces produce oxide metal.
Bettis Atomic Power Laboratory	West Mifflin, PA	Nuclear fuels, Government, research and development.
Cerac Inc.	Milwaukee, WI	Produces ceramics.
Chicago Magnesium Casting Corp.	Blue Island, IL	Magnesium thorium alloys.
Coleman Co. Inc.	Wichita, KS	Produces thoriated mantles.
Controlled Castings Corp.	Plainview, NY	Magnesium thorium alloys.
General Atomics Inc., ¹	San Diego, CA	Nuclear fuels.
W.R. Grace & Co., Davison Chemical Div.	Chattanooga, TN	Capability to produce compounds from monazite.
GTE Sylvania	Towanda, PA	Produces thoriated welding rods.
Hitchcock Industries Inc.	South Bloomington, MN	Magnesium thorium alloys.
Phillips Elmet	Lewiston, ME	Produces thoriated welding rods.
Rhône-Poulenc Basic Chemicals Co.	Freeport, TX	Produces thorium nitrate from an intermediate compound of monazite.
Spectrulite Consortium Inc.	Madison, IL	Magnesium thorium alloys.
Teledyne Cast Products	Pomona, CA	Do.
Teledyne Wah Chang	Huntsville, AL	Produces thoriated welding rods.
Union Carbide Corp., nuclear div.	Oak Ridge, TN	Nuclear fuels; test quantities.
Wellman Dynamics Corp.	Creston, IA	Magnesium thorium alloys.
Westinghouse Materials Co. of Ohio ²	Cincinnati, OH	Capability to produce compounds and metals; manages DOE thorium stocks.

¹Formerly G A Technologies.

²Manager of Department of Energy stocks.

TABLE 3
U.S. FOREIGN TRADE IN THORIUM AND THORIUM-BEARING MATERIAL

(Quantity in kilograms unless otherwise specified)

	1989		1990		1991		Principal destinations and sources, 1991	
	Quantity	Value	Quantity	Value	Quantity	Value		
EXPORTS								
Thorium ore, monazite, concentrate	50,000	\$29,780	(¹)	(¹)	(¹)	(¹)		
Compounds	8,247	221,323	220	\$68,409	2,649	\$154,493	Hong Kong 1,361; Canada 850; Japan 350; Angola 40; Other 48.	
IMPORTS								
Ore and concentrate	metric tons	774	530,294	800	685,650	(¹)	(¹)	
ThO ₂ content		48,240	XX	56,000	XX	—	XX	
Thorium ore metal, excluding monazite	metric tons	250,381	37,126	188,624	33,292	205,100	31,157	Turkey 129,177; Norway 41,898; Canada 28,485; Zimbabwe 1,944; other 3,596.
Compounds		33,344	943,692	18,598	594,811	42,609	1,270,421	France 42,347; Netherlands 142; United Kingdom 120.

¹Estimated. XX Not applicable.

²No foreign trade data reported for this category.

Sources: Bureau of the Census and a producer.

TABLE 4
MONAZITE CONCENTRATE: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons, gross weight)

Country ²	1987	1988	1989	1990	1991
Australia	12,813	11,872	*13,000	*11,000	5,000
Brazil	4,332	2,817	1,900	*2,000	2,000
India ³	4,000	4,000	4,300	*3,500	5,000
Malaysia	2,908	2,920	2,948	*3,323	1,900
South Africa, Republic of ³	1,200	1,200	1,200	*1,317	1,300
Sri Lanka ³	200	200	200	200	200
Thailand	458	590	631	*377	400
United States	W	W	W	W	W
Zaire	97	168	175	*124	120
Total	26,008	23,767	*24,354	*21,841	15,920

¹Estimated. ²Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

³Table includes data available through Apr. 22, 1992.

⁴In addition to the countries listed, China, Indonesia, North Korea, the Republic of Korea, Nigeria, and the U.S.S.R. may produce monazite, but output, if any, is not reported quantitatively, and available general information is inadequate for formulation of reliable estimates of output levels.

TIN

By James F. Carlin, Jr.

Mr. Carlin, a physical scientist with the Branch of Metals, has been the commodity specialist for tin for 12 years. Domestic survey data were prepared by Elsie Isaac, mineral data assistant; and international data tables were prepared by William L. Zajac, Chief, Section of International Data.

Tin was one of the earliest metals known to humankind. Tin occurs in nature mostly as the oxide mineral cassiterite. Tin metal is commonly used as a protective coating or as an alloy with other metals. It finds applications in products and processes as diverse as tin cans, solder for electronics, tin chemicals, bronze fittings, and flat-glass production. Its strategic importance is exemplified by the fact that it generally has been the largest dollar-volume holding of all metals in the National Defense Stockpile (NDS) since the establishment of the stockpile in the 1940's.

In 1991, for the 11th consecutive year, there was an excess of tin on the world market. Excess stocks were believed to be about 40,000 metric tons of tin at yearend.

The price of tin remained in a fairly narrow band throughout the year and at a level that was low by historical standards. World tin mine output declined as producers reduced output in view of continued low tin prices. In the United States, there was continued interest in the recycling of used tin cans largely due to the rising costs and limited space of landfills.

DOMESTIC DATA COVERAGE

Domestic consumption data for tin are developed by the U.S. Bureau of Mines from a voluntary survey of U.S. tin users. All of the 290 consumers to which a survey request was sent responded. (See table 1.)

BACKGROUND

Definitions, Grades, and Specifications

Primary or virgin tin metal is cast and sold as bars, ingots, pigs, and slabs in weights of 50 kilograms or less. Most of the tin metal imported into the United States is in the form of 45-kilogram pigs. During 1982-84, the American Society of Testing and Materials (ASTM) Pig Tin Task Group developed a new specification for grade-A tin, calling for 99.8% minimum tin content and 0.030% maximum bismuth content. This specification bore the code B-336-90. In 1990, the American Tin Traders Association modified the silver content of tin to be 0.01% maximum. This action was taken to limit some tin metal that was being imported into the United States with high silver content, which was thought to be detrimental to the electronic soldering industry.

Products for Trade and Industry

Tin is rarely used in its pure form, but is usually alloyed with other metals. Bronze, developed in the fourth millennium B.C., traditionally was a copper-base alloy containing about 10% to 15% tin to harden the copper. Today, the term "bronze" is seldom used without a modifier because it is applied also to some copper-base alloys containing no tin. The most important tin bronzes are the phosphor bronzes, containing up to 12% tin with small additions of phosphorus, and the gun metals, which are tin-bronze casting alloys containing

from 1% to 6% zinc. Brass, another old and important alloy, is primarily an alloy of copper and zinc, but often tin is a component.

There are numerous solder compositions, typical of which are tin-silver solder (95% tin, 5% silver), antimony-tin solder (95% tin, 5% antimony), and soft solders (ranging from 1% to 70% tin, with the remainder essentially lead).

Tin-base babbitt is an alloy containing antimony and copper, used for lining bearings. Lead-base babbitt metal contains 1% to 10% tin.

Compositions for tin foil and "white metal" vary with the producer. Most foil now is a tin-lead alloy. Some foil is made from relatively pure tin or tin containing small amounts of copper or antimony hardener. White metals, such as britannia metal, jewelers metal, and pewter, are tin alloys, normally hardened with antimony. Pewter may have a wide range of composition, but high-grade pewter contains 90% to 95% tin, with 1% to 2% copper and the remainder antimony. Copper and antimony serve as hardeners.

Tinplate is a thin-gauge steel sheet product that has a very thin tin coating on both surfaces; the steel thickness and the weight of surface tin coating vary according to end-use requirements. Terneplate is sheet steel coated on both surfaces with a tin-lead alloy.

Tinplate is commonly shipped as coil, solder as ingot, bronze as strip or plate, and brass as any of these forms. Each of these semifinished products is then used to fabricate a wide variety of end-use items. Brass and bronze are also

produced in cast forms. Tin usually becomes a very small, but essential, part of the end-use item's weight or cost.

Industry Structure

At least 35 countries mine or smelt tin. Virtually every continent has an important tin-mining country. Most operations are privately owned, but many are publicly owned. A similar situation exists in the tin-smelting industry.

In the major Southeast Asian tin-producing countries, small, labor-intensive, high-unit-cost mines, such as gravel-pump mines, produce a significant proportion of total output. In these same countries, massive, expensive dredges also are used. Large, privately owned mining enterprises operate in Southeast Asia, but many of the operations are also Government-owned. The four largest tin-mining companies in the market economy countries are Paranapanema in Brazil, the Malaysia Mining Corp., P.T. Timah in Indonesia, and Corporación Minera de Bolivia (COMIBOL).

An agreement establishing the Association of Tin Producing Countries (ATPC) came into force on August 16, 1983. The five charter members were Bolivia, Indonesia, Malaysia, Thailand, and Zaire. Australia and Nigeria joined later. The stated objectives of the ATPC were to obtain fair returns for tin producers and adequate and stable supplies at reasonable prices for tin consumers, to facilitate cooperation in the marketing of tin, and to enhance the growth of tin use. Members stated that they viewed the ATPC as complementary and supportive of the activities of the ITC. The Tin Council was an association of leading world tin producer and user countries that attempted to stabilize tin prices and supply-demand from 1956 until its demise in 1989. In recent years, the most visible activity of the ATPC has been to attempt to reduce the world oversupply of tin through a series of supply rationalization schemes. These programs have essentially featured export-control limits placed on the seven member countries. While these programs have succeeded in drastically reducing the

huge tin oversupply, they have not eliminated it largely because major producers such as Brazil and China were not bound by the guidelines of the programs.

U.S. mine production of tin has been negligible for many decades. Small quantities of tin concentrates are produced from placer deposits in Alaska, and small quantities were once produced in several Western States.

In recent decades, the only tin smelter in the United States was the Texas City, TX, facility of TexTin Corp. In recent years, this smelter treated tin concentrates imported from Bolivia and Peru, as well as some domestic tin concentrates and some accumulated secondary residues. In 1989, owing to continued low tin prices and difficulties in obtaining feedstocks, TexTin ceased tin production and converted its equipment to process secondary copper.

The tinsplate-producing industry is quite concentrated, comprising only seven major steel firms. The solder-producing industry is considerably more dispersed, but most of the tonnage is accounted for by a relatively few soldermaking firms. During the past decade, both the tinsplate and the solder industries have undergone considerable consolidation. In the tin chemical field, while there are a number of companies, one firm dominates.

The other domestic tin-using industries are diverse, such as the brass, bronze, solder, and flat-glass industries, and are represented by hundreds of firms and plants. Most are in the East and Midwest.

Geology-Resources

Tin is a relatively scarce element; its average abundance in the Earth's crust is about 2 parts per million (ppm), compared with 94 ppm for zinc, 63 ppm for copper, and 12 ppm for lead. Tin is preferentially concentrated by magmatic differentiation processes and shows a worldwide affinity for granitic rocks or their extrusive equivalents. The principal deposits are scattered irregularly along a belt surrounding the Pacific Ocean. Most of the world's tin is produced from placer

deposits; about one-half of placer tin comes from Southeast Asia.¹

The only mineral of commercial importance as a source of tin is cassiterite (SnO₂), although small quantities of tin are recovered from the complex sulfides stannite, cylindrite, franckeite, canfieldite, and teallite. Cassiterite has a high specific gravity (6.8 to 7.1), a Moh's scale hardness of 6 to 7, and is usually a dark-brown or black color with an adamantine luster.

Because cassiterite is both heavy and chemically inactive, it is concentrated in residual (eluvial) placers that form over or adjacent to bedrock source areas where weathering and erosional processes remove lighter rock materials and gravity assists in downslope movement of heavy minerals released by weathering. The richest placers are stream deposits (alluvial placers) found where flowing water has concentrated heavy minerals generally derived from residual placers. Ocean beach sands may also contain placer accumulations of tin; such placers are mined offshore in Indonesia and Thailand. No extensive tin placer deposits have been found in the conterminous United States.

Technology

Exploration.—Historically, prospecting for tin has been carried out by the time-honored methods of panning, drilling, and pitting. As rich deposits were exhausted and the costs of exploration rose, the search for tin required more sophisticated methods. Geophysical and geochemical analyses have been employed to cover large areas more rapidly, isolating areas of possible tin deposits so that drilling can be more effective and less costly.

Mining.—Principal methods for mining placer deposits are bucketline dredging and gravel-pump operations, although hydraulicking and various open pit methods are also used. The bucketline dredges used are floating dredges similar to those used to mine other placer deposits. The ore is excavated and transported by buckets to the interior of the dredges, washed on screens, and

concentrated in jigs and on shaking tables. Tailings are discharged at the rear of the dredges to fill in the mined pond, and the crude tin concentrate is sent to the dressing shed for final concentration.

Although gravel-pump and hydraulic mining both use water jets to break up the tin-bearing material, the methods of conveying the material to the launders differ. In gravel-pump mining, a pump is used, whereas hydraulicking employs the pressure developed by a natural head of water. In each method, the material is washed through a riffled launder, called a palong in Malaysia, where the cassiterite is collected by the riffles and the waste is washed away.

In open pit operations, the material is excavated by power shovels and transported on a conveyor belt to the washing plant for treatment.

Vein tin deposits are mined by methods similar to those used in the hard-rock mining of other nonferrous ores. Access to the ore bodies is by adits and shafts. The ore is broken by conventional drilling and blasting and transported from the mine to a concentrator for treatment.

Processing.—The crude tin concentrate from placer mining is further upgraded by washing, tabling, and magnetic or electrostatic separation. The final product is virtually pure cassiterite.

Tin ore from lode deposits is reduced to the necessary size by conventional crushing and grinding. The ore is concentrated by gravity methods involving screening, classification, jigging, and tabling. The gravity concentrate is usually of lower grade than placer concentrate owing to associated sulfide minerals. The sulfide minerals are removed by flotation or magnetic separation, with or without roasting, to produce a second-stage concentrate.

Cassiterite in placer deposits is fairly coarse grained, and recoveries range from 90% for gravel-pump mines to 95% for dredging operations. However, the cassiterite in vein deposits is very fine grained and is difficult to recover by gravity concentration. Cassiterite ore at mines in Australia, Bolivia, the Republic

of South Africa, and the United Kingdom are floated, but recoveries are seldom more than 70%. Recovery of the tin content in Bolivia is reportedly as low as 50%.

Cassiterite is reduced to tin by heating with carbon at 1,200° to 1,300° C. The almost pure cassiterite concentrate from placer deposits is smelted directly. Other concentrates, particularly from Bolivia, contain impurities that must be removed before smelting. This is usually done by roasting the tin concentrates with or without fluxes, followed by acid leaching. During roasting, most of the sulfur and arsenic are removed as oxides. Bismuth, copper, iron, and zinc oxides are removed by leaching the roasted concentrate with sodium carbonate or sulfate and leaching with water. Antimony, bismuth, lead, and silver may be removed by a chloridizing roast, followed by an acid leach.

In modern tin-smelting plants, reverberatory furnaces are used to smelt primary tin concentrate and to resmelt the slag for additional tin recovery. Although blast and electric furnaces are also used to smelt tin concentrate, reverberatories are often preferred because of better control, cleaner slags, and superior efficiency in smelting finely divided materials. Electric furnaces are often favored for energy-saving reasons, especially for smaller smelters.

Tin smelting is a batch operation. A typical charge consists of cassiterite concentrate, a carbon reducing agent, and limestone and silica fluxes. From 10 to 12 hours is required to smelt a charge. When smelting is complete, the molten batch is tapped into a settler, from which the slag overflows into cast-iron pots. The molten tin from the bottom of the settler is cast into slabs or pigs for refining.²

The slag, containing 10% to 25% tin, is resmelted to yield a slag containing less than 1% tin.

Heat treatment is the most widely used refining method and consists of heating the tin from smelters on a inclined hearth to a temperature slightly above the melting point of pure tin, but below the melting points of the impurities. Thus,

the comparatively pure tin melts and flows into a kettle, leaving impurities such as iron and copper in a dross residue that is retreated to recover the contained tin.

The molten tin is then stirred with green wood, which produces a strong boiling action. During the stirring, the metal impurities and part of the tin are oxidized and form an oxide dross that is skimmed off. Sometimes tossing is used instead of stirring. In this operation, hand ladles of molten tin are dipped from and poured back into the kettles, exposing the tin to the oxidizing action of the air. After refining has been completed, the tin is cast into pigs for marketing.

Recycling.—The only form of tin recycling in which free tin is produced is detinning. In recent decades most detinning has been conducted on new, flat tinplate scrap, mostly from tin mills or canmaking plants. In the detinning of flat tinplate, generally the tinplate scrap is treated with a hot solution of caustic soda in the presence of an oxidizing agent to dissolve the tin as sodium stannate. The base steel is then washed and compacted into bales for shipment. The tin may be recovered from the stannate solution as metal, sodium stannate crystals, or tin oxide. Because of advantages in processing costs and production of a high-purity metal, the common practice is electrolysis of the stannate solution to yield metallic tin. The refined tin averages as high as 99.99% purity, with antimony, iron, and lead as common impurities.

Until recent years, the detinning of used tin cans was not performed on an economic, high-volume basis because cans were often in a crushed condition and had enamel coatings and food particles attached that made effective detinning impossible. However, in the late 1980's, techniques were developed to detin these used tin cans. The most common method is to shred the cans into small popcorn-sized pieces and then proceed with the caustic soda treatment.

Most scrap tin is alloyed tin (such as solder, brass-bronze, or babbitt) that is recycled in its own alloy industry. These

producers refine out undesired elements from the scrap charge or may use additions to build up desired elements.

Byproducts and Coproducts

In some tin placer deposits, large amounts of columbium, tantalum, and rare-earth minerals are associated with the cassiterite. Some lode tin deposits contain numerous other materials such as copper, lead, silver, and zinc, usually in the form of sulfides.

Tin has been recovered as a coproduct of molybdenum mining at the Climax lode mine in Colorado. Small quantities have been produced as a coproduct of placer gold mining or tailings-cleanup operations in Alaska or South Dakota. It has been produced as a byproduct of lead-zinc mining in Ontario and British Columbia, Canada.

In some major tin-producing countries, such as Malaysia and Thailand, tantalum contained in tin smelter slags is a major source of tantalum supply.

Substitutes

Alternative materials, often less costly, have been a significant factor in the downward trend in domestic tin consumption over the past two decades. Aluminum and chromium-coated tin-free steel were two materials used to replace tinplate in beverage cans over the past two decades. Other substitutes for tinplate include enameled steel, glass, paper, and plastics. Nonmetallic materials, aluminum, copper, and galvanized steel have largely replaced terneplate for roofing and both tinplate and terneplate for other construction. In general, no satisfactory substitutes have been found for tin in solder, although lowering the tin content of the solder may be possible in some applications. Aluminum alloys, other copper-base alloys, and plastics could be substituted for some bronzes. Low-tin aluminum-, copper-, or lead-base bearing alloys and roller or ball bearings may be substituted for babbitt metal. Other chemicals may replace some tin chemical compounds for use as fungicides, biocides, marine

antifouling paints, or polyvinyl chloride stabilizers.

ANNUAL REVIEW

Legislation and Government Programs

The National Defense Stockpile (NDS) continued in its third year of being managed by the Department of Defense, with day-to-day operations guided by the Defense Logistics Agency (DLA).

The DLA sold 6,195 tons of tin from the stockpile in 1991. Through April 18, the disposals were direct sales to the marketplace; then on that date, and for the balance of the year, DLA recommenced its earlier tin swap program with the ferroalloy upgraders and also continued its cash sales to industrial users. The direct sales were held each day, with orders for lots of 5 tons or more being accepted daily between 1:30 p.m. and 3:30 p.m. at the price set by the DLA for that day. Pickup points for the stockpile tin were Point Pleasant, WV; Curtis Bay, MD; Hammond, IN; and Stockton, CA. The DLA had authority from Congress to dispose of 12,000 tons in fiscal 1991. At yearend 1991, the NDS inventory was 162,994 tons of tin and the stockpile goal was 42,674 tons.

On February 7, a bill (S. 391) was reintroduced calling for either a ban or reduction in the use of lead in certain products. On August 1, the bill was reported out to the Senate by the subcommittee on toxic substances. No further action was taken on the bill during 1991. Certain features of the bill calling for drastic lowering of lead content could be of special importance for tin because tin is often a coalloy of lead.

Strategic Considerations

Tin's strategic importance is indicated by its major position in the NDS. Tin is used in such defense-related products as solder for printed circuit boards used in aircraft and night-vision weaponry, and brass or bronze fittings and gears for naval needs. Tin in the NDS is stored in warehouses around the country, often

close to plants that would use the tin during wartime.

It is considered unlikely that domestic tin deposits will yield significant amounts of tin in the next 10 years, so the Nation's strategic needs must be met by imports, the NDS, and recycling.

Issues

Throughout the year major tin-producing countries and some tin traders voiced their displeasure with the increased pace of NDS tin disposals and the prospect of an even faster pace in future years. They argued that the disposals made in these higher annual quantities disrupted the tin market and depressed the price of tin.

In December, the U.S. Government announced that unwrought and alloyed forms of tin from China were being targeted, along with a host of other items, for possible penalty duties of up to 100% starting in 1992. The U.S. Trade Representative's office was taking the action in response to allegedly insufficient protection of U.S. intellectual property rights by the Government of China. Tin was one of only three metal categories listed as possible tariff targets; the rest of the items, numbering in the hundreds, were primarily textiles.

Production

The Cache Creek Mine, in the Toftoy District near Manley Hot Springs, AK, was the only mine in the United States to produce significant amounts of tin concentrates. The tin was recovered as a byproduct of gold mining. The mine, owned by Shoreham Resources, Inc., Houston, TX, was in its second year of production. The tin output from the mine amounted to only a small fraction of domestic tin requirements.

Early in the year, Alco-Met Corp., Boston, MA, started production of high-grade tin at its Boston plant. The firm intended to fill part of the gap left by the closure of the Capper Pass tin smelter in the United Kingdom. The plant's initial capacity is 100 tons annually of 99.9999% pure tin. Such purities are

avored for certain electronic applications.

The United States was believed to be the world's largest producer of secondary tin. Tin metal recovered from new tinplate scrap and from used tin cans was the only type of secondary tin available in the marketplace as free tin; other secondary tin was available in scrap materials as an alloying ingredient. Secondary tin from recycled fabricated parts was used in many kinds of products and was a major source of material for the solder and the brass and bronze industries. The Steel Can Recycling Institute (SCRI) in Pittsburgh, PA, funded by five domestic tinplate producers, sought to advance the collection, preparation, and transportation of can scrap. SCRI expanded its program of having representatives in various regions of the United States work with municipalities, scrap dealers, and detinners to promote the recycling of tin cans. Until 1989, generally all detinning operations treated only new (factory-generated) tinplate scrap. This usually came from steel plant tin mills or canmaking plants. Little or no old scrap, such as that from used (post consumer) tin cans, was detinned. This was partly due to the availability of relatively inexpensive and nearby landfills, which in earlier years could readily accept municipal trash; but mostly it was due to technical difficulty in processing the cans. These used cans typically have enamel coatings, outside paper wrappers, remnants of food particles, and are often crushed, making it difficult to treat them effectively with chemical detinning solutions on a high-volume basis. However, in recent years, new scrap preparation procedures were developed, especially a new shredding method, that permitted detinning of used tin cans. Also, municipalities, by the late 1980's, faced increased costs for disposing of trash in landfills and the dwindling of landfill sites. These developments began to set the stage by 1990 for large-scale detinning of used tin cans. The domestic detinning industry responded with the construction of several new plants.

In 1990, Proler International Corp. started up the world's largest detinning facility in Houston, TX. This new plant was capable of recycling 163,000 metric tons of tinplated steel cans and clippings annually, the equivalent of 2.5 billion tin cans. This operation involved the shredding of feedstock followed by continuous detinning in a series of rotating cylinders. The separated products were sold to various foundries and steelmakers. Plans were announced for the establishment of a new \$260 million steel minimill, a joint venture of Proler International Corp., Birmingham Steel Corp., and Danielli & C. Officine Meccaniche S.p.A. (Italy). An important feature of the new operation was an ensured supply of detinned can scrap generated by Proler's new Houston detinning plant. The new minimill was to be constructed on the site of the USX Corp.'s former Baytown, TX, steelworks. Plans were scuttled when Birmingham Steel withdrew from the deal. Then in 1991, Proler closed its new continuous detinning plant, reportedly because it had strong competition from steel mills buying tinplate scrap directly from tin mills, canmakers, and municipalities and charging this scrap (with the tin still on it) directly into their furnaces on a diluted basis.

During 1991, steelmakers, who depended on significant amounts of used tin cans to meet the scrap steel needs of their furnaces, moved up the learning curve and found they could accept higher levels of tin in their scrap charge than they believed several years earlier.

AMG Resources Corp. continued operating its new tin can recycling plant in St. Paul, MN. The facility had an electrolytic detinning system with a capacity to process up to 40,000 metric tons of mostly used tin cans annually. (See table 2.)

Consumption and Uses

Primary tin consumption remained about the same as that in the prior year. The major consumption categories of tinplate and solder had slight decreases in

consumption, while chemicals registered a small increase.

Early in the year, USX Corp. announced that by yearend it would permanently close the steel production section of its Fairless Works, north of Philadelphia, PA. The closure would affect about 2,000 of the plant's 3,100 employees and entail the shuttering of the plant's blast furnaces, open-hearth furnaces, a slag mill, and a hot strip mill. The plant's tin mill would continue to operate, with hot band coils being supplied from USX's Mon Valley Works near Pittsburgh, PA. By yearend, the Mon Valley Works was expected to have its new continuous slab caster in operation. The present Fairless Works had no continuous caster, and continuously cast slabs are an important ingredient for top quality, flat-rolled steel products such as tinplate.

Tinplated steel and tin-free steel accounted for 27% of the 130 billion cans shipped domestically; aluminum accounted for 73%. This compared to 1990 figures showing steel accounting for 29% of the 126 billion cans shipped domestically and aluminum accounting for 71%. Aluminum held an overwhelming advantage in the beverage can market, while steel predominated in the food can and the general-line markets.³ (See tables 3, 4, 5, and 6.)

Recycling

The Waupaca Foundry Co., Waupaca, WI, commenced a new pilot program utilizing used tin cans as a charge for its furnaces. Waupaca is the second largest cast iron foundry in the country, pouring about 2,200 metric tons of iron daily in its four plants. Previously, the foundry industry had considered that the tin levels in used tin cans were so high as to possibly have harmful metallurgical effects. However, Waupaca's experience indicated that higher amounts of tin can be tolerated than previously thought. Used tin cans make up as much as 40% of the material charged into the foundry's cupola furnace. The firm also had an electric furnace but the used tin cans had not yet been tried in it. The State of

Wisconsin had in recent years passed a strict recycling law that phases out acceptance of certain materials such as batteries, waste oil, and appliances for landfill. Many expected that in a few years, tin cans will be added to the list of material banned from landfills.

AMG Resources Corp., based in Pittsburgh, PA, announced that its new detinning and tin can recycling facility in St. Paul, MN, operated smoothly in its first full year. On the Mississippi River, the plant had an initial capacity to process 40,000 metric tons per year of used steel food, beverage, paint, and aerosol cans, and other ferrous materials. The plant was built on the basis of a 20-year guaranteed purchase contract to process about 20,000 metric tons annually of magnetically separated ferrous materials from the municipal waste stream. The balance of the plant capacity is filled mainly from curbside collection programs in Minnesota. Some material is also received from The Dakotas, Iowa, and Wisconsin.

USX Corp., a major producer of tinsplate, expanded its metal beverage container recycling operations into three more States in the South. The firm installed Coinbak reverse vending machines at 280 gasoline-convenience stores in Alabama, Florida, and Georgia. These combination service stations and food stores are operated by Marathon Oil Co., a subsidiary of USX, and the rest are Ecol and Starvin' Marvin outlets. The Coinbak reverse vending machines return one penny for each 12-ounce steel or aluminum beverage can. USX began installation of the container recycling devices at Emro stores in 1989 in Indiana and Ohio, and the program was expanded in 1990 to stations in North Carolina and South Carolina. With the newest additions, about 400 Emro stations in 7 States in the Midwest and South now are equipped with reverse vending machines. There are about 1,700 Emro-managed service station and convenience stores spanning 21 States in the Midwest and throughout the Southeast. The used cans are gathered from the machines by Nationwide Recyclers Inc., a division of Crown, Cork & Seal Co., and sold to

U.S. Steel to be remelted in the firm's steelmaking furnaces. Used cans from the newly installed machines in Alabama, Florida, and Georgia were to be shipped to USX's Fairfield Works in Birmingham, AL. Steel melt shops can charge bimetal tin cans (steel bodies and aluminum tops) into their furnaces; the aluminum is useful as a deoxidizing agent in the steelmaking process.

The Steel Can Recycling Institute (SCRI) announced that the 1991 overall recycling rate for steel cans was 34%, compared with a 1990 rate of 25%. This new rate brings the SCRI a step closer to its 1995 goal of a 66% recycling rate, which would match the steel industry's current overall recycling rate. The 1991 steel food can recycling rate was 37%, a dramatic increase over the 1990 rate of 26%. The 1991 recycling rate for steel beverage cans (often called bimetal cans) was 46%. The 1991 recycling rate for general-line cans was 12%.

In 1991, the SCRI began the development of a data base through which information on steel can recycling programs, on a national basis, may be obtained. By late 1992, SCRI expected that this data base would be used in conjunction with a toll-free number, allowing consumers to call to obtain information on programs and collection locations.

Also in 1991, SCRI, through its regional offices, began to encourage and assist communities in adding empty steel paint and aerosol cans to their recycling programs.

Markets and Prices

Marketing of tin metal in the United States was performed mostly through trading firms, which imported the tin from a variety of countries and warehoused it in this country until they sold it to customers. Some tin was also marketed directly in the United States by large foreign producers who maintained sales offices here and sold their tin metal, usually on a 1-year contract basis, only to the largest users. Among these direct-sale operations were Indo-Metal Corp. and Renison Consolidated Goldfields Corp.

Most traders and direct-sale operations were based in the New York, NY, area. The year was one of consolidation after the significant shakeout in the tin trading community. Foreign-owned trading firms seemed to dominate the field.

The price of tin metal, as published in Metals Week, remained in a narrow band all year. The LME remained the primary trading focus for tin. The Kuala Lumpur Commodities Exchange in Malaysia continued as an active tin trading forum. (See table 7.)

Foreign Trade

Bolivia remained the major source of U.S. tin metal imports. China ranked second, followed by Brazil, Indonesia, and Malaysia.

Imports of tin in all forms (ore and concentrate, metal, and waste and scrap) remained free of U.S. duty. (See tables 8, 9, and 10.)

World Review

The Executive Committee of ATPC met in Kuala Lumpur, Malaysia, March 5-8. Five of the seven member countries were represented, with Nigeria and Zaire not represented. As usual, non-ATPC member Brazil sent an observer. The Committee reviewed progress on ATPC's Fifth Supply Rationalization Scheme (SRS), which is intended to cut into surplus world stocks by limiting tin exports of member countries in 1991 as follows: Malaysia, 28,556 tons; Indonesia, 28,376 tons; Thailand, 17,116; Bolivia, 12,611 tons; Australia, 6,937 tons; Zaire, 1,351 tons; and Nigeria, 901 tons, for a total of 95,849 tons.

Capacity.—The data in table 11 represent rated annual production capacity for mines and smelters on December 31, 1991. Rated capacity was defined as the maximum quantity of product that can be produced in a specific period on a normally sustainable, long-term operating rate, based on the physical equipment of the plant and routine operating maintenance. Capacity includes both

operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period with minimum capital expenditure. Estimates of the rated capacities of mines and smelters were based on discussions with officials from private industry, on past and present production rates, and on published capacity data. (See table 11.)

Australia.—The Renison Bell Mine in Tasmania, owned by Renison Consolidated Goldfields Ltd., remained the largest tin mine, accounting for more than 90% of Australia's total mine output. It was the world's largest hard-rock underground tin mine and a relatively low-cost producer with substantial high-grade reserves.

During the year, Renison suffered a lengthy period of inactivity due to labor strife, and when it resumed production, it did so with 30% fewer employees. Most of the firm's mine output was shipped to either the DKS or Malaysia Smelting Co. tin smelters in Malaysia for refining. The Renison material was an important feedstock for both smelters, which reportedly operated at only 50% to 70% capacity during Renison's difficulties.

Greenbushes Ltd. continued to mine tin and tantalum near Perth, in Western Australia. This operation produced about 200 to 300 metric tons of tin-in-concentrate annually in recent years. A major project to develop underground access to the tin-tantalite ore body was completed. Other improvements included the construction of a 300,000-metric-ton-per-year integrated mining and processing operation. With these additions, it was expected that tin output would be increased to about 1,200 metric tons annually, with one-half of that coming from the underground mine.

Broken Hill's Port Kembla steel plant was announced to be the site of a new tin recycling facility. The plant would detain and recycle tin cans and other ferrous scrap. The facility was to be owned by Australian Metal Recovery Ltd. (AMR), a subsidiary of Edward C. Levy Co. (USA). Renison continued direct sales of refined tin to large American consumers

from an affiliate office in Green Cove Springs, FL. (See tables 11, 12, and 13.)

Bolivia.—This was a year of consolidation for the Bolivian tin industry, after several years of rapidly increasing production.

Traditionally, the Huanuni tin mine, in the Department of Oruro, has been the richest underground tin mine in Bolivia. The capacity of the mine is 3,600 metric tons of tin-in-concentrate annually, with the output being delivered to the Vinto metallurgical complex of Corporación Minera de Bolivia (COMIBOL). Huanuni experienced a 1-month strike over pay for its 1,200 workers. Lost output due to the strike was estimated to be 300 tons. Other important operations were the Catavi-Siglo tin mine in the Department of Potosí, leased by COMIBOL to four cooperatives employing 4,500 miners; and the Caracoles tin mine in the Department of Potosí, with reported reserves of 3,900 metric tons.

At midyear, Government mining ministry officials announced that the large Brazilian tin-mining company, Paranapanema, had won the bidding for the tin tailings and dumpings at the Siglo-Catavi Mine. Paranapanema offered to invest \$8 million in Siglo-Catavi, which has an estimated 21 million tons of dumpings. The only other company to bid was Tympten Ltd. (Australia). Siglo had been the world's largest underground tin mine before it was closed in 1986. Several small mining cooperatives currently work the mine.

Following the tender by Bolivia's COMIBOL for the sale of its Bolivar tin-silver-zinc-lead operation, a local concern called COMSUR (in which RTZ Ltd. has a one-third interest) offered to build a 1,000-metric-ton-per-day milling plant, to start in 1993. COMIBOL estimated Bolivar to have 856,000 metric tons of reserves (1.26% tin) and more than 350,000 tons of tailings (0.76% tin). Reportedly, other bids were made by Carnon Consolidated Ltd., Tiwanacu, Consolidated Goldfields Ltd., and the

Metall Mining Group (a Metallgesellschaft A.G. subsidiary).

During the year, reports indicated somewhat of a lessening of the active market in smuggling tin concentrates from Brazil into Bolivia. Still, some tin mined in Brazil shows up on statistical tables as being of Bolivian origin.

Bolivia was, for the second straight year, the major source of tin for the United States.

Brazil.—Brazil lost its position as the world's leading producer of mined tin; it ranked third in 1991. It remained the world's largest tin smelter. Tin mines and smelters were mostly privately owned. Tin was mined from both alluvial and lode deposits. Brazilian mines were generally considered the lowest cost to operate in the world. Brazil was not a member of ATPC, but generally agreed to cooperate with the spirit of its guidelines and restrict its tin exports.

The Paranapanema Group was the largest private tin producer in the world, owning and operating six tin mines. The mines were Capipore in the State of Amapa, Massangana (also known as C-75, Ariqueemes, and Serrinha) in the State of Rondônia, São Francisco in the State of Mato Grosso, São Raimundo in the State of Pará, and Iarape Preto and Pitinga, both in the State of Amazonas.

Pitinga, the country's largest tin mine, used four Elliot bucket wheel dredges and mined to a depth of 6 to 8 meters. The mine site employed nine floating wash plants and seven gravel-pump plants. The dredging capacity was about 13 million cubic meters annually. Management was in the process of developing mining of a soft weathered tin ore, separate from the alluvium, and reportedly was considering constructing a tin smelter. Total investment at Pitinga was about \$115 million.

Paranapanema announced the creation of a new subsidiary, Paranapanema USA Inc. The new unit was to be based in Providence, RI, and was to serve as a direct sales office in the United States for the firm's refined tin, thereby bypassing the traditional traders. This new

arrangement replaced an agreement whereby Cookson America Inc. acted as North American sales agent for Paranapanema.

The São Francisco Mine in Mato Grosso State was sold at midyear by the Paranapanema Group to the garimpeiros cooperative, Coopegro, for a reported \$1 million. Up to 4,000 garimpeiros were expected to eventually work at the mine site, producing gold and tin concentrates. In 1991, the mine produced about 200 metric tons of tin-in-concentrates.

At midyear, the Government closed tin-mining operations by independent miners at the Bom Futuro Mine near Ariquemes, in Rondônia State. The action was prompted by charges that independent tin miners were involved in the drug trade and by increased concern over environmental damage caused by uncontrolled mining in the area. The Government stated that any future operation of the mine would have to be by an organized entity (either a mining company or a garimpeiros cooperative) to ensure the needed investment of several millions of dollars to satisfy environmental requirements. At yearend, the Infrastructure Ministry was finalizing a decree that would allow Empresa Brasileira de Estanho SA (Ebesa), a consortium of seven companies headed by Paranapanema, to reopen and exploit the Bom Futuro Mine. Although mining at the site was prohibited, reportedly moderate amounts of tin-in-concentrate were being smuggled out. At its peak in 1989, about 20,000 garimpeiros worked at Bom Futuro producing 30,000 metric tons of tin-in-concentrates annually. The Bom Futuro closure was the largest factor in Brazil's large decline in tin mine production in 1991.

Reports indicated that within a year of its startup, Reynolds Metals Corp.'s aluminum can plant in Brazil captured virtually the entire beer and beverage can market there. Among the reasons cited were that an aluminum can is only one-third the weight of a tin can, even though the aluminum can is three times the cost. Brazil's tinplate producers believed they could regain market share once they adopted two-piece-can technology.

Burma.—Mining Corp. Two, based in Rangoon, was responsible for the country's entire production of tin, as well as antimony, tungsten, and other metals. The organization totaled about 1,000 persons who operated various underground, opencast, gravel-pump, and dredge tin operations, as well as a tin concentrator at Tavoy. The country's tin ore was smelted at the Syriam smelter, with a capacity of 1,000 metric tons annually.

Burundi.—Tin has been mined here since the 1930's, across the northern part of the country, where small pits are worked by local artisans. The deposits of cassiterite are alluvial although vein lodes are known to exist. Tungsten and occasionally columbium-tantalum minerals are often associated with the tin minerals. Production is typically reported as containing 60% to 70% tin oxide, which is sold to ore buyers in Bujumbura who accumulate it and ship it to smelters.

Canada.—Rio Algom Ltd. announced it would close its East Kemptville, Nova Scotia, tin mine in early 1992. Discovered as a tin property in 1979, the mine started production in 1985 and had a series of owners. The mine's shutdown had been anticipated by industry sources for the past year. Rio had provisions of \$20 million to cover closing costs. Rio is 53% owned by RTZ Ltd., and the demise of this mine represented the end of RTZ's involvement in tin mining, since in 1991 RTZ's other tin holdings (all based in the United Kingdom) ceased operations.

The Mount Pleasant tin-tungsten-molybdenum property in New Brunswick was purchased by Novagold Resources Ltd. from Billiton Metals Canada Ltd. and Lac Minerals Ltd. for \$10 million. Mount Pleasant began operations as a producer of molybdenum and tungsten in 1983 and closed in 1985 due to depressed prices. During 1991, Babcock Contractors Co. undertook a feasibility study, and by 1992, a decision on whether to restart production, this time as a tin-base mine, was to be made. Reportedly, minable underground

reserves total 5.1 million tons grading 0.70% tin; in addition, drill-inferred near-surface reserves total 5 to 10 million tons grading 0.30% tin.

China.—Yunnan Tin Corp., a subsidiary of China National Nonferrous Metals Industry Corp. (CNNC), Gejiu City, Yunnan Province, was the largest tin producer. It operated 5 underground mines, 7 open pit mines, 10 mineral dressing plants, and 1 smelter, giving it an annual mine production capacity of 7.5 million tons of tin ore, while the smelter capacity was 20,000 tons of refined tin yearly. Both surface alluvial deposits and underground lode deposits were worked. After 100 years of exploitation, the high-grade alluvial deposits were virtually depleted. In 1990, low-grade alluvial tin ores of fine particle size, tailings, and underground lodes were the main sources.

Yunnan used reverberatory smelting of tin concentrate, pyrometallurgical refining of tin metal, electrolytic separation of tin-lead alloy, and tin slag fuming. It used a continuous electrothermal crystallizer for removal of lead and bismuth, using the different melting points and specific gravities of tin and lead-tin alloy; direct recovery of tin was increased by 6% over former methods and staffing levels were reduced by 50%. Several other tin smelters around the world utilized Yunnan crystallizer technology.

The Dachang Mining Administration (a subsidiary of CNNC) in Dachang, Nandan Xian, Guangxi Zhuangzu Zizhiqu, continued its expansion program that was expected to eventually make it China's largest tin mine.

Germany, Federal Republic of.—The Government enacted tough new laws aimed at reducing the volume of waste materials. The new rules call for reduced use of materials for packaging and regulations for packaging specifications. The laws encourage private industry to implement these, but also set deadlines when the Government will determine whether its targets have been reached. By 1993, the law mandates a 60% recycling rate for glass; 40% for tinplate;

30% for aluminum, paper, cardboard, and plastics; and 20% for mixed materials. By 1995, the recovery rates must be 90% for tinplate.

In the former East Germany, high operating costs and environmental problems caused the closure of the only tin smelter, in Saxony. The firm was previously known as VEB Altenburg, before changing to Saxonea A.G. in 1990 when Germany was reunited. Depressed tin prices and low-grade feedstock also contributed to the plant's demise. Tin concentrates were sourced locally but contained just 3% to 5% tin and high amounts of sulfur. Output of sulfur dioxide during the smelting process was too high to meet German emission standards, and pollution-abatement equipment could not be afforded. The plant employed 840 workers. All tin produced was consumed domestically.

The VIAG Group announced the purchase of Continental Can Europe for more than \$1 billion from the Peter Kiewit Co. of Omaha, NE. The purchase made VIAG Europe's third largest canmaker after Pechiney and CMB Packaging.

Indonesia.—Tin mining was performed mostly offshore, usually by means of large-scale dredging. P.T. Tambang Timah (P.T. Timah), the Government-owned mining firm, ranked as one of the world's largest tin-mining organizations and accounted for about 80% of Indonesia's tin output. Formerly, P.T. Timah's three primary tin production complexes were on the islands of Bangka, Belitung, and Singkep, with the Bangka Island facilities accounting for 70% of P.T. Timah's tin production.

During the year, P.T. Timah embarked on a stringent restructuring program designed to bring its costs in line with the depressed tin price. It closed its operations on Belitung and Singkep Islands, consolidated its tin production on Bangka Island, and moved its headquarters from Jakarta to Bangka Island.

P.T. Timah sold its tin output in the United States exclusively through its

subsidiary, Indo-Metal Corp., in New York, NY.

Italy.—The city government of Genoa announced plans to move steel production at the Cornigliano Works to other locations. The steel plant is part of Italy's large Government-owned Italsider. Under the plan, known as Project Utopia, Italsider's tin mill would be relocated to the Cantieri Metallurgici Italiani Works at Naples. Italsider's tin mill at Genoa has an annual capacity of 435,000 tons of tinplate.

Japan.—The Ministry of International Trade and Industry (MITI) announced a new Action Program on recycling. The program raises the recycling rate target for both aluminum and steel cans to 60% by 1994. In 1990, the recycling rates were 43% for aluminum and 45% for steel cans. One feature of the program would be that aluminum and steel cans each bear distinctive markings for easy separation. The aluminum cans would have a triangle mark and the steel cans a circle mark. Since the program covers imported cans also, MITI is trying to obtain approval from member countries of the General Agreement on Tariffs and Trade (GATT).

Korea, Republic of.—The Korea Zinc Co. announced it would cease producing refined tin this year. Closure of its 1,800-ton-per-year smelter was attributed to the rising cost of feedstock and weak tin prices. The smelter produced 850 tons of tin in 1990. In recent years, the smelter had been modified to treat dirty, low-grade concentrates supplied from China. The other Korean tin producer, Lucky Metal Co., has a small smelter at Changhang and reportedly was planning to cut its production by 30% to 40% because of the rising cost of feedstock. Import tariffs on tin, which in 1991 amounted to 10% of the value, are scheduled to be reduced to 7% in 1992 and to 5% in 1993. This was expected to render local tin production uncompetitive.

Pohang Iron & Steel Co. (POSCO) announced the opening of a new plant to

produce 120,000 tons of tinplate annually. Pohang is one of the world's largest tinplate producers.

Malaysia.—Malaysia Mining Corp. (MMC) remained the largest tin producer in the country, but continued low tin prices depressed its operations. MMC had been mostly dependent on its tin operations until recent years, but for the second year continued the expansion of its exploration program in other base metals and gold in several countries, including Brazil, Burma, China, Laos, and Vietnam. MMC was already active in engineering and construction and announced plans to enter manufacturing. Diversification plans included one joint venture to set up a plant to make video tapes and another to build a plant to make car components. In the minerals field, MMC planned to assess the feasibility of mining sulfide and oxide ores at the Mengapur base metals project, a search for alluvial diamonds in Indonesia, and gold exploration in Brazil. In 1991, only 16 of MMC's tin dredges out of a total of 38 were operating.

MMC announced the sale of a 12% interest in Austral Amalgamated Tin to a local firm called Global Stature. Austral operated two dredges, and its production averaged 450 tons of tin-in-concentrate annually.

Construction was completed on a second tinplating line at the tin mill operated by Perstima. The new line doubled the plant's capacity to 180,000 tons annually. Perstima was partially owned by Kawasaki Steel Co. (Japan), and the technology for the line was supplied by Kawasaki. Perstima announced that the new line was designed to permit later installations that could produce tin-free steel as well as tinplate. Tinplate demand in Malaysia was about 130,000 tons annually.

The main producing State, Perak, announced cessation of renewal of leases for idled tin mines. The land would instead be redeveloped and turned over to industrial and agricultural uses. Many gravel pump mines in Perak closed down in 1991. Gravel-pump mines accounted for 40% of Malaysia's tin mine

production until closures this year. About 50 gravel pumps were active in Perak, compared with more than 20 in 1985.

Many of the Chinese gravel-pump miners in Perak have left the industry, and it is believed that even if the tin price were to climb to the \$4 per pound level, very few would reenter mining. The All-Malaya Chinese Miners' Association announced that as many as 30% of the gravel pump mines currently operating could close down by 1992 owing to continuing low tin prices. The association asked the Government for increased subsidies, particularly for energy, which accounts for 40% of production costs.

The large Derak Keramat Smelter (DKS) announced that it had started to produce 99.99% and 99.999% tin at a new electrorefining plant. DKS planned to reach its targeted production of 10 to 20 tons monthly by yearend.

The other large tin smelter, the Malaysian Smelting Corp. (MSC), also announced plans to produce a premium high-grade electrolytic tin with a minimum 99.99% purity. Production capacity was 100 tons annually. MSC operates a 60,000-ton annual capacity tin smelter at Butterworth, Penang, and the newly constructed unit to produce 99.99% tin would be an adjunct to that. A major factor in both DKS' and MCS' decision to enter this specialized field was the decision by the Capper Pass tin smelter in the United Kingdom to close this year; Capper Pass had produced about 99.99% tin for years. MSC officials stated that the high-purity tin would be marketed in 12.5 kilogram bars, rather than the normal 29.5-kilogram bars used for the Straits and MSC brands.

The Government eliminated the export duty on several commodities, including tin, on January 1, 1991. The export duty on tin had averaged 11%.

Mexico.—Tin mining was focused in the north-central region in the three adjoining States of Durango, Zacatecas, and San Luis Potosí. The country's main

tin mine, the El Perro Mine, was owned by Cia. Mineral Pizzuto.

Estañó Electro S.A. de C.V. operated a tin smelter at Tlalnepantla, near Mexico City. Fundidora de Estañó S.A. operated a tin smelter at San Luis Potosí. Metales Potosí S.A. had a smelter in San Luis Potosí as did Minera de Rio S.A. Most of the tin concentrates processed by the four smelters was imported, primarily from Canada and China.

Netherlands.—Billiton Ltd. announced plans to cease production of primary tin and secondary lead at its smelter in Arnhem. Billiton's decision to close the plant, which has a capacity of 4,000 tons of tin and 10,000 tons of secondary lead annually had been somewhat expected. Some of the factors in the firm's decision were: current low tin and lead prices, the need to make a substantial investment to modernize the lead side of the facility to meet environmental regulations, a persistent oversupply of tin ingot inventory worldwide, and a worldwide excess of tin smelter capacity relative to tin mine capacity. Another possible factor may have been recurring problems with the new Siromelt technology installed about 2 years ago on the tin side of the plant and which reportedly kept it running far below capacity. Production of tin tetrachloride, tin anodes and granules, and tin foil were to continue. The shutdown was to take place gradually during the first half of 1992.

Nigeria.—Tin was mined from alluvial deposits by two major companies: Consolidated Tin Mines Ltd. and Nigerian Tin and Allied Minerals Products Ltd. Cassiterite was mined in association with columbite, tantalite, and tungsten minerals. All tin concentrates were shipped to the sole tin smelter, the Government-owned Makeri Smelting Co., in Jos, Plateau State. Makeri continued to operate well-below capacity.

Substantial amounts of tin concentrates were reportedly smuggled out of the country. The Government officially permitted only refined tin to be exported, on which a 15% royalty per ton was charged. These exports were then

marketed by London-based Decacia International Ltd.

Portugal.—Somincor S.A. announced that the medium-grade concentrate circuit at its copper-tin mine at Neves Corvo was now in full production. Somincor signed a contract with the DKS smelter in Malaysia to smelt some of its output; it already had existing contracts with Billiton (The Netherlands), Malaysia Smelting Co., and Zamora (Spain). In 1991, Somincor expected to increase its mine output of low-grade (25% tin) and medium-grade (45% tin) concentrates. The firm looked ahead to 1992 when full-year production from its medium-grade concentrate circuit would be effective.

Singapore.—A severe shortage of high-grade tin concentrates forced the closure of the Kimetal tin smelter. The smelter had a nameplate capacity of 11,000 tons of tin annually, but this was never fully realized. Two electric arc furnaces operated in conjunction with two tin crystallizers. The crystallizers had refining rates of 3.5 and 8 tons per day. Both were designed and built in-house and were expected to be sought after once the plant was sold. Crystallizers are simple yet efficient mechanisms to remove metallic impurities from low-grade, dirty concentrates; most Chinese tin concentrates are both low-grade and dirty. Although Kimetal treated these grades, the plant operated more effectively on higher grades that did not damage sections that clogged up with impurities. Kimetal sourced high-grade tin concentrates principally from Africa, Australia, and China. All three sources had supply difficulties and could no longer effectively feed Kimetal's demand. Kimetal began operations in 1978 and was believed to have processed large amounts of nonquota tin concentrates from surrounding countries, including China, Indonesia, Malaysia, and Thailand. Kimetal faced strong competition from the two large Malaysian smelters, Datuk Keramat Smelting Co. and Malaysian Smelting Co., both of which had cost advantages owing to economies of scale.

Spain.—Altos Hornos de Vizcaya (AHV), one of Spain's two leading steel producers, reached an agreement with AMG Resources Ltd. (United Kingdom) to cooperate on tinplate recycling in Spain. AMG would be acting in an advisory capacity to Spain's municipal authorities to help introduce various used tin can collection schemes that have proved effective in the United Kingdom. Also, AMG would supply technology for the separation and processing of tinplate scrap from domestic waste. AHV is Spain's largest tinplate producer, with a current output of about 250,000 tons annually. Initially, it was planned to process all collected tinplated materials at an existing detinning plant in Rioja; as the program expanded, likely new plant sites were Madrid, Bilbao, and Barcelona.

Thailand.—Once the country's largest revenue producer among metals, tin continued to decline in relative importance. Other industries such as tourism, real estate, rubber, palm oil, and shrimp farming drew investment away from tin mining in the south where most tin reserves were located.

In addition, the rising tide of environmentalism affected mining in tourist areas and closed off Government forest areas from mining. In 1991, only 130 tin mines were operating, less than one-half the total before the 1985 "tin crisis." All 42 tin mines on the tourist island of Phuket were closed.

Toward yearend, Thai Pioneer Enterprise Co. announced plans to reopen its Pathum Thani tin smelter in early 1992. The plant had been closed since 1981. The firm said that the reopening was now possible since it had agreed with its creditors to restructure its \$16 million debt. The smelter's capacity is 5,000 tons of tin metal annually, and it was expected to process both domestic and imported tin concentrates.

Siam Tin Plate Co., a joint venture between Japanese and Thai firms, was launched. Initially, the steel black plate coils would be supplied by Nippon Steel Corp. (Japan). The plant would have a

capacity of 200,000 tons of tinplate annually.

United Kingdom.—The country's dwindling tin-mining activity continued to be focused in the historic Cornwall mining district. Mining costs here were reportedly among the highest in the world.

Carnon Holdings Ltd. announced the shutdown of its two mining operations and the termination of its entire 415-member work force. Carnon attributed the closure to a recent decision by the Government's Department of Trade and Industry to stop providing funds under an existing \$48 million loan agreement. The Government had originally agreed to the loan to assist in a 1988 employee purchase of Carnon in the aftermath of the collapse of the International Tin Council and its price support mechanism. In past years, the two Carnon tin mines, South Crofty and Wheal Jane, had been among the world's highest operating cost tin mines. But since 1986, Carnon had been able to reduce the average cost of producing 1 ton of tin-in-concentrate at these two mines by 50%, to about \$7,680 per ton. At the more efficient South Crofty operation, production costs had been lowered to about \$6,720 per ton and were still falling. Carnon intended to immediately flood the Wheal Jane Mine, making it unlikely the mine will ever be reopened. An application was entered to transform part of the site into a recreational complex. Mining at South Crofty also ceased, although Carnon maintained facilities there in hopes of attracting outside investors to reactivate the mine.

Tin mine operator Geevor Ltd. merged with the European Mining Finance Corp. Ltd., a mining fund company listed on the Luxembourg Stock Exchange. The Geevor tin mine near Pedeen, in the Cornwall district, has been under care and maintenance since 1990.

U.S.S.R.—Tin mining was conducted mostly in the far eastern regions of the country. The Khingansk tin mine in eastern Siberia proceeded with plans to expand its tin concentrate output to 3,000

tons annually by 1995 from 1,200 tons currently. Recently discovered deep tin ore bodies extended the mine's life.

A fire reportedly stopped production indefinitely in the tin mill of the Karanganda Steel Works in Kazakhstan. The blaze began when an oil line on the temper mill ruptured, completely destroying three electrolytic tinplating lines. Almost one-half of the tinplate used in the Soviet canning industry is produced in this tin mill, and there were fears that this outage would aggravate already existing food shortages. The U.S.S.R. reportedly sought emergency tinplate imports from several Western countries.

Zimbabwe.—The Government announced plans to privatize the country's largest tin mine, the Kamativi Mine. Legislation was expected to be passed that would enable the mine to be sold by the nationalized Zimbabwe Mining Development Corp. (ZMDC) to private investors or other mining corporations. Kamativi has been a high-cost producer and has had continuing financial problems since the 1985 international "tin crisis" and subsequent low market prices. ZMDC took over Kamativi in 1987 from the Industrial Development Corp. At midyear, ZMDC announced the layoff of 900 people out of a total work force of 1,362. The aim was to reduce costs. Underground mining was to be gradually phased out. Future production would be from the open pit section of the mine.

Current Research

In the United Kingdom, AEA Industrial Technology Ltd. announced development of a new type of catalyst for automobile catalytic converters that uses a mixture of tin oxide and various other oxides such as those of copper, chromium, and aluminum. It would compete with the widely used platinum-rhodium combination. It is produced using a process known as sol-gel, which involves the mixing of the catalyst with a solvent; the mixture is then applied to the substrate in the form of a rubbery gel by spinning or dipping. The solvent is later

driven off, leaving a solid catalyst. The main advantage of the sol-gel technique is that it gives control over the particle size during the preparation process, providing a more porous catalyst and thus a large surface area for the chemical conversion reactions to take place on. The tin oxide catalyst would be cheaper to produce than precious-metal materials, but offers no advantage in lower operating temperatures. Legislation in Europe, the world's largest car market, will require catalytic converters on all cars by January 1993.

In the United Kingdom, Vertifoam International Ltd. announced development of a new approach to polyurethane foam production. For years, both organo-tin and inorganic tin compounds have found substantial use as important industrial catalysts, with one of those applications being the production of polyurethane polymers. The worldwide consumption of these compounds in the production of polyurethanes is estimated to be about 3,000 tons annually. Polyurethanes form a wide range of materials, including flexible and rigid foams, solid elastomers, hard coatings, and adhesives. Flexible foam is usually produced using either slab or molding techniques. Vertifoam's new procedure has the foam conveyed vertically instead of horizontally. Among the claimed advantages are a thinner outer skin with lower trim losses, a more uniform foam density, greater efficiency of chemical usage, and much lower emission of hazardous vapors.

Also in the United Kingdom, the International Tin Research Institute announced development of a stable, noncyanide electrolyte for depositing a wide range of tin-zinc alloy coatings. Tin-zinc coatings have excellent corrosion resistance and are considered potential alternatives to cadmium in many applications. Until now, however, they could be deposited only from a cyanide-base bath, which is difficult to operate on a production scale. The new, nontoxic solution is reported to have good throwing power, produces dense and nonporous deposits, and is suitable for rack, barrel, and brush plating.

OUTLOOK

Supply

The supply of tin for the United States is expected to continue to originate primarily in Asia and South America and to enter the country in the form of refined tin metal. While some promising tin deposits exist in the United States, primarily in Alaska, these are not expected to become major production sites during the next 10 years, especially if tin prices remain low. The NDS is expected to continue to be a modest source of tin supply because the stockpile goal is substantially lower than the current inventory. Increased scrap recovery, both through alloy recycling and detinning, is a possibility, and that could help ameliorate the Nation's dependence on imported tin.

Worldwide, the oversupply of tin that has existed since the early 1980's appears likely to persist for at least a few more years. The advent of several new tin mines in countries like Brazil and China appears likely.

Demand

The demand for primary tin in the United States is forecast to be static in the next few years. There appears to be some chance that tinplate may regain a small portion of the beverage can market in the next few years, especially if tin can recycling increases and if tinplate can maintain or widen its cost advantage over aluminum.

Among the major metals, tin has had a relatively good record with regard to toxicity and the environment, and this aspect may help tin gain market share at the expense of more troublesome metals. In particular, if regulations continue to negatively impact the use of lead in applications such as solder, the demand for tin as the complimentary alloy component may increase.

Worldwide, new tinplating lines are being built in developing countries, and tinplate traditionally is a stronger competitor than aluminum in canmaking

markets outside of the United States. Therefore, the outlook for overall tin demand is for modest growth of about 1% annually in the next few years.

Numerous research efforts in recent years have resulted in new applications for tin that could result in small-scale increases in tin consumption in future years, but there have recently been no major new applications.

¹Taylor, R. G. *Geology and Tin Deposits*. Elsevier Science Publishing Co., 1979, 543 pp.

²Pearce, S. C. *Developments in Smelting and Refining of Tin*. Paper in *Lead-Zinc-Tin '80*, ed. by J. M. Cigan, T. S. Mackey, and T. J. O'Keefe (Proc. Symp. on Metall. and Environmental Control, Las Vegas, NV, Feb. 24-28, 1980). Metall. Soc. AIME, 1979, pp. 754-769.

³Can Manufacturers Institute. *Metal Can Shipment Report 1991*. Washington, DC, 1991, p. 1-4.

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TABLE 1
SALIENT TIN STATISTICS

(Metric tons unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Production:					
Mine	W	W	W	W	W
Smelter	'3,905	'1,467	'1,000	—	—
Secondary ¹	16,159	15,275	14,340	'17,187	NA
Exports ²	1,318	1,209	904	658	970
Imports for consumption:					
Metal	41,150	43,493	33,988	33,810	29,102
Ore (tin content)	2,953	2,837	216	—	1
Consumption:					
Primary	35,620	'37,531	'36,609	'36,770	35,111
Secondary	8,599	8,072	'9,854	'8,395	7,920
Stocks, yearend, U.S. industry	14,464	15,023	14,668	'17,304	13,802
Prices, average cents per pound:					
New York market	309.01	330.91	397.28	287.69	258.75
Metals Week composite	418.78	441.42	520.18	386.29	362.85
London	NA	NA	'382.00	281.00	254.00
Kuala Lumpur	303.45	319.86	387.12	276.02	248.42
World: Production:					
Mine	'179,902	'204,370	'233,202	'218,395	'196,695
Smelter:					
Primary	'188,156	'214,058	'218,868	'222,737	'204,758
Secondary	'16,204	19,482	19,133	'18,150	'15,606

¹Estimated. ²Revised. NA Not available. W Withheld to avoid disclosing company proprietary data; U.S. mine production for 1987-91 was negligible.

³Reported figure.

⁴Excludes reexports.

⁵The London Metal Exchange resumed trading as of June 1, 1989.

TABLE 2
SECONDARY TIN RECOVERED FROM SCRAP PROCESSED AT DETINNING AND OTHER PLANTS IN THE UNITED STATES

		1990	1991
Tinplate scrap treated	metric tons	W	W
Tin recovered in the form of:			
Metal	do.	'215	234
Compounds (tin content)	do.	W	W
Total	do.	'215	234
Weight of tin compounds produced	do.	W	W
Average quantity of tin recovered per metric ton of tinplate scrap used	kilograms	2.73	2.20
Average delivered cost of tinplate scrap	per metric ton	\$112.59	\$104.30

¹Revised. W Withheld to avoid disclosing company proprietary data.

**TABLE 3
U.S. CONSUMPTION OF PRIMARY AND SECONDARY TIN**

(Metric tons)

	1987	1988	1989	1990	1991
Stocks, Jan. 1 ¹	9,876	10,217	9,242	13,551	12,500
Net receipts during year:					
Primary	38,401	39,421	37,760	38,473	36,113
Secondary	11,707	12,472	10,901	9,501	1,601
Scrap	6,635	6,707	8,168	6,534	6,616
Total receipts	56,743	58,600	56,829	54,508	44,330
Total available	66,619	68,817	66,071	68,059	56,830
Tin consumed in manufactured products:					
Primary	35,620	37,531	36,609	36,770	35,111
Secondary	8,599	8,071	9,854	8,395	7,920
Total	44,219	45,602	46,463	45,165	43,031
Intercompany transactions in scrap	512	630	424	316	275
Total processed	44,731	46,232	46,887	45,481	43,306
Stocks, Dec. 31 (total available less total processed)	21,887	22,586	19,184	22,563	13,520

¹Revised.

¹Includes tin in transit in the United States.

**TABLE 4
TIN CONTENT OF TINPLATE PRODUCED IN THE UNITED STATES**

Year	Tinplate waste (waste, strips, cobble, etc., gross weight) (metric tons)	Tinplate (all forms)		
		Gross weight (metric tons)	Tin content ¹ (metric tons)	Tin per metric ton of plate (kilograms)
1987	141,842	2,302,173	10,357	4.5
1988	149,054	2,375,809	11,582	4.9
1989	153,542	2,263,769	11,764	5.2
1990	156,419	2,467,205	11,750	4.8
1991	166,647	2,468,769	11,482	4.7

¹Includes small tonnage of secondary tin and tin acquired in chemicals.

TABLE 5
U.S. CONSUMPTION OF TIN, BY FINISHED PRODUCT

(Metric tons of contained tin)

Product	1990			1991		
	Primary	Secondary	Total	Primary	Secondary	Total
Alloys (miscellaneous) ¹	W	W	W	W	W	W
Babbitt	552	211	763	662	206	868
Bar tin	603	—	603	444	W	444
Bronze and brass	¹ 1,163	2,003	³ 3,166	1,198	1,662	2,860
Chemicals	6,275	W	6,275	6,564	—	6,564
Collapsible tubes and foil	W	W	W	W	W	W
Solder	¹ 11,718	⁴ 4,725	¹ 16,443	10,785	4,920	15,705
Tinning	1,707	W	1,707	1,459	W	1,459
Tinplate ²	11,750	W	11,750	11,482	W	11,482
Tin powder	563	W	563	539	W	539
Type metal	W	W	W	W	W	W
White metal ³	1,045	W	1,045	728	W	728
Other	1,394	¹ 1,456	² 2,850	1,250	1,132	2,382
Total	³36,770	⁸8,395	⁴45,165	35,111	7,920	43,031

¹Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."

²Includes ternite metal.

³Includes secondary pig tin and tin acquired in chemicals.

⁴Includes pewter, britannia metal, and jewelers' metal.

TABLE 6
U.S. INDUSTRY YEAREND TIN STOCKS

(Metric tons)

	1987	1988	1989	1990	1991
Plant raw materials:					
Pig tin:					
Virgin ¹	6,466	7,013	6,807	10,671	10,355
Secondary	2,333	1,440	2,253	⁷ 795	863
In process ²	1,289	1,056	1,032	¹ 1,101	974
Total	10,088	9,509	10,092	¹12,567	12,192
Additional pig tin:					
Jobbers-importers	1,890	3,387	3,536	2,467	742
Afloat to United States	2,486	2,127	1,040	2,270	868
Total	4,376	5,514	4,576	4,737	1,610
Grand total	14,464	15,023	14,668	¹17,304	13,802

¹Revised.

²Includes tin in transit in the United States.

³Data represent scrap only, tin content.

TABLE 7
MONTHLY COMPOSITE PRICE OF STRAITS TIN FOR DELIVERY IN NEW YORK

(Cents per pound)

Monthly	1990			1991		
	High	Low	Average	High	Low	Average
January	417.12	384.10	402.87	370.02	249.09	368.22
February	388.64	374.29	380.40	367.81	361.47	364.88
March	402.36	382.52	387.71	365.42	357.32	360.75
April	404.51	386.45	394.17	377.88	339.91	362.04
May	394.03	385.81	389.37	373.11	363.50	368.34
June	385.46	368.38	376.34	372.84	365.12	368.95
July	372.98	361.47	367.30	369.05	365.64	367.07
August	401.62	382.66	390.26	368.88	360.81	365.06
September	401.14	375.57	380.19	362.94	358.01	360.76
October	405.54	390.69	399.32	361.18	356.89	358.62
November	400.13	381.94	394.40	358.25	353.67	355.19
December	379.83	366.01	373.21	357.39	351.84	354.27
Average	XX	XX	386.29	XX	XX	362.85

XX Not applicable.

Source: Metals Week.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TIN, TIN MANUFACTURES, TINPLATE AND TERNEPLATE, AND TINPLATE SCRAP

Year	Miscellaneous tin and tin manufactures			Tinplate and terneplate		Tin compounds		Tinplate scrap	
	Tinfoil, tin powder, flitters, metallics, tin and manufactures, n.s.p.f.	Dross, skimmings, scrap, residues, tin alloys, n.s.p.f.		Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
		Value (thousands)	Quantity (metric tons)						
1989	\$4,570	10,270	\$34,695	321,883	\$216,516	314	\$2,720	10,785	\$1,903
1990	2,086	6,788	35,291	293,426	199,036	426	2,493	8,488	1,782
1991	1,867	5,855	33,132	276,326	195,659	245	1,906	10,109	2,240

Source: Bureau of the Census.

TABLE 9
U.S. EXPORTS OF TIN, TINPLATE, AND TERNEPLATE IN VARIOUS
FORMS; EXPORTS OF INGOTS, PIGS, BARS; EXPORTS OF TINPLATE
SCRAP

Year	Tinplate and terneplate		Ingots, pigs, and bars ¹		Tin scrap ²	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousand)
1989	178,884	\$101,279	904	\$8,915	—	—
1990	145,396	78,687	658	3,344	—	—
1991	150,187	89,677	970	5,455	—	—

¹Revised.

¹Ingots and pigs only; excludes bars.

²Includes bars, rods, profiles, wire, powders, flakes, tubes, and pipes.

Source: Bureau of the Census.

**TABLE 10
U.S. IMPORTS FOR CONSUMPTION OF TIN, BY COUNTRY**

Country	Quantity (metric tons)	Value (thousands)
1990		
Metal (unwrought tin):		
Australia	1,660	\$10,352
Bolivia	8,472	52,581
Brazil	6,535	41,558
Chile	628	4,662
China	4,339	26,280
Germany, Federal Republic of:		
Eastern states	60	374
Hong Kong	284	1,688
India	280	1,918
Indonesia	4,695	28,872
Malaysia	3,873	24,474
Mexico	2,614	20,630
United Kingdom	227	1,568
Other	143	906
Total	33,810	215,863
1991		
Concentrates (tin content):		
Bolivia	1	6
Total	1	6
Metal (unwrought tin):		
Australia	1,105	6,559
Belgium	221	1,238
Bolivia	8,912	47,907
Brazil	4,489	24,414
Burma	119	659
Chile	927	4,794
Germany, Federal Republic of:		
Eastern states	—	—
China	5,281	29,752
Hong Kong	515	2,870
India	164	925
Indonesia	4,425	24,974
Malaysia	1,751	9,701
Mexico	671	4,753
Singapore	100	566
United Kingdom	344	2,160
Other	76	455
Total¹	29,102	161,725

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 11
TIN: WORLD ANNUAL MINE AND PRIMARY SMELTER CAPACITY,
BY CONTINENT AND COUNTRY, DECEMBER 1991

(Metric tons)

Continent and country	Mine capacity	Smelter capacity
North America:		
Mexico	600	7,000
United States	300	—
South America:		
Argentina	1,000	1,000
Bolivia	20,000	32,000
Brazil	60,000	50,000
Peru	8,000	—
Europe:		
Czechoslovakia	300	300
Germany:		
Eastern states	2,000	3,000
Netherlands	—	7,000
Portugal	6,000	2,000
Spain	—	14,000
U.S.S.R.	20,000	20,000
United Kingdom	5,000	12,000
Africa:		
Cameroon	200	—
Namibia	1,500	—
Niger	300	—
Nigeria	2,000	3,000
Rwanda	2,000	2,000
South Africa, Republic of	3,000	3,000
Swaziland	100	—
Tanzania	100	—
Uganda	100	—
Zaire	4,000	1,000
Zambia	100	—
Zimbabwe	2,000	2,000
Asia:		
Burma	2,000	1,000
China	45,000	45,000
Indonesia	35,000	32,000
Japan	—	2,000
Korea, Republic of	100	2,000
Laos	1,000	—
Malaysia	40,000	120,000
Thailand	30,000	44,000
Vietnam	1,000	1,000
Oceania: Australia	10,000	2,000
Total	302,700	408,300

TABLE 12
TIN: WORLD MINE PRODUCTION, BY COUNTRY¹

(Metric tons)

Country	1987	1988	1989	1990	1991 ²
Argentina	186	446	405	¹ 123	—
Australia	7,691	7,009	7,709	¹ 7,425	² 5,630
Bolivia	8,128	10,504	15,849	¹ 17,249	² 16,863
Brazil	30,405	44,102	50,232	39,149	29,300
Burma	939	529	501	634	650
Burundi ³	²	² 4	¹ 50	¹ 70	70
Cameroon	8	5	5	¹ 4	4
Canada	² 779	³ 591	² 790	² 828	2,700
China ⁴	20,000	29,500	40,000	¹ 42,000	43,000
Czechoslovakia	550	515	562	¹ 613	600
Germany, Federal Republic of: Eastern states ⁵	² 400	² 500	² 500	¹ 1,800	1,000
Indonesia	26,093	29,590	31,263	30,200	² 30,061
Japan	86	—	—	—	—
Korea, Republic of	3	—	—	—	—
Laos	⁴ 50	300	281	¹ 500	550
Malaysia	30,388	28,866	32,034	28,468	² 20,710
Mexico	369	274	159	¹ 7	15
Mongolia ⁴	1,200	1,200	¹ 1,200	³ 20	250
Namibia	1,097	1,182	1,120	⁹ 00	100
Niger	94	119	71	⁷ 0	70
Nigeria	844	432	350	² 27	200
Peru	5,263	⁴ 181	5,053	5,134	² 6,559
Portugal	64	81	63	1,404	² 3,100
Rwanda ⁴	—	¹ 18	762	⁷ 34	730
South Africa, Republic of	1,438	1,377	1,306	1,140	² 1,042
Spain	71	66	64	49	40
Tanzania ⁴	4	4	3	3	3
Thailand	14,852	14,225	14,922	14,635	² 14,937
Uganda ⁴	10	10	10	10	10
U.S.S.R. ⁴	16,000	16,000	16,000	15,000	13,500
United Kingdom	4,003	3,454	3,846	³ 400	1,100
United States	W	W	W	W	W
Vietnam ⁴	680	700	850	900	900
Zaire ⁵	2,378	² 771	2,346	² 221	1,800
Zambia	17	1	1	¹	1
Zimbabwe ⁴	1,410	1,140	1,300	1,300	1,200
Total	¹ 179,902	² 204,816	² 233,607	² 218,518	196,695

¹Estimated. ²Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

³Contained tin basis. Data derived in part from the Monthly Statistical Bulletin of the International Tin Council, London. Table includes data available through June 30, 1992.

⁴Reported figure.

⁵Concentrates gross weight reported, estimated 47% Sn content.

⁶Concentrates gross weight reported, estimated 70% Sn content.

⁷Nonduplicated total of content of concentrates plus smelter production.

TABLE 13
TIN: WORLD SMELTER PRODUCTION, BY COUNTRY¹

(Metric tons)

Country	1987	1988	1989	1990	1991*
Argentina:					
Primary	240	280	² 280	³ 85	—
Secondary*	100	100	100	100	100
Total*	340	380	380	185	100
Australia:					
Primary	563	439	424	³ 312	² 268
Secondary*	300	300	300	² 200	200
Total*	863	739	724	⁵ 512	468
Belgium: Secondary	3,900	4,972	⁵ 5,000	⁶ 6,063	6,000
Bolivia: Primary	2,667	5,373	9,448	¹² 12,567	12,200
Brazil:					
Primary	29,446	41,857	44,240	³⁹ 39,149	40,000
Secondary*	200	250	250	250	250
Total*	29,646	42,107	44,490	³⁹ 39,399	40,250
Burma: Primary	309	110	500	² 276	200
Canada: Secondary*	200	200	200	200	200
China: Primary*	20,000	29,500	²⁹ 29,500	³⁵ 35,000	38,000
Czechoslovakia: Primary	545	515	562	⁶ 613	600
Denmark: Secondary*	100	100	100	100	100
Germany, Federal Republic of:					
Eastern states: Primary	² 2,400	2,500	² 2,500	3,000	—
Western states: Secondary	250	150	300	⁵ 500	600
Total	2,650	2,650	2,800	3,500	600
Greece: Secondary*	40	40	40	40	30
India: Secondary	100	200	200	² 200	200
Indonesia: Primary	24,200	28,365	29,916	30,389	³⁰ 30,415
Japan: Primary	895	846	808	816	⁶ 692
Korea, Republic of: Primary*	400	400	800	800	600
Malaysia: Primary	44,363	49,945	⁵⁰ 50,874	⁴⁹ 49,002	⁴² 42,722
Mexico: Primary	1,734	1,538	1,590	¹ 1,600	1,600
Netherlands:					
Primary	3,834	3,478	4,529	⁵ 5,500	5,950
Secondary*	180	180	190	² 250	250
Total*	4,014	3,658	4,719	⁵ 5,750	6,200
Nigeria: Primary	560	566	258	³ 310	300
Norway: Secondary*	60	55	100	100	90
Portugal: Primary and secondary	48	22	62	¹ 1,404	1,500
Singapore: Primary*	1,000	900	600	800	200
South Africa, Republic of:					
Primary	1,508	1,389	1,307	1,152	¹ 1,076
Secondary*	350	400	400	350	350
Total*	1,858	1,789	1,707	1,502	1,426
Spain:					
Primary	1,671	806	1,767	⁶ 600	1,000

See footnotes at end of table.

TABLE 13—Continued
TIN: WORLD SMELTER PRODUCTION, BY COUNTRY¹

(Metric tons)

Country	1987	1988	1989	1990	1991 [*]
Secondary [*]	200	200	200	200	200
Total[*]	1,871	1,006	1,967	[†]800	1,200
Thailand: Primary	15,438	14,675	14,571	15,512	[‡]11,255
U.S.S.R.:[*]					
Primary	18,500	18,500	18,000	16,000	13,000
Secondary	4,000	4,000	4,000	3,700	3,300
Total	22,500	22,500	22,000	19,700	16,300
United Kingdom:					
Primary	12,135	9,014	3,584	[†] 6,122	1,500
Secondary	4,871	7,757	7,184	[†] 5,897	3,736
Total	17,006	16,771	10,768	[†]12,019	[‡]5,236
United States:					
Primary	3,927	1,467	1,000	—	—
Secondary	1,353	578	569	W	W
Total	5,280	2,045	1,569	W	W
Vietnam: Primary [*]	645	600	800	800	800
Zaire: Primary [*]	[‡] 90	[‡] 118	100	[†] 90	80
Zimbabwe: Primary	1,038	855	848	[†] 838	800
Grand total	[†]204,360	233,540	238,001	[†]240,887	220,364
Of which:					
Primary	[†] 188,156	[†] 214,058	[†] 218,868	[†] 222,737	204,758
Secondary	[†] 16,204	19,482	19,133	[†] 18,150	15,606

^{*}Estimated. [†]Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

¹Data for 1987 derived in part from the Monthly Statistical Bulletin of the International Tin Council, London and, for 1988-90, UNCTAD. Wherever possible, total smelter output has been separated into primary (from ores and concentrates) and secondary (tin metal recovered from old scrap). This table reflects metal production at the first measurable stage of metal output. Table includes data available through June 30, 1992.

[‡]Reported figure.

TITANIUM

By Joseph Gambogi

Mr. Gambogi, a physical scientist with 9 years of Government and industry experience, has been a commodity specialist since 1988. Domestic survey data were prepared by Giovanni C. Jacarepaqua, statistical assistant; international data tables were prepared by William L. Zajac, Chief, Section of International Data.

Titanium (Ti) is a lightweight metal well known for corrosion resistance and its high strength-to-weight ratio. Titanium comprises about 0.62% of the Earth's crust and occurs primarily in the minerals anatase, brookite, ilmenite, leucoxene, perovskite, rutile, and sphene. Although titanium is best known for its use as a metal alloy, titanium is primarily used in the form of titanium dioxide (TiO_2) and is used widely as a white pigment in paints, paper, and plastics. Other minor uses of titanium minerals include ceramics, chemicals, welding rod coatings, heavy aggregate, and steel furnace flux.

Global demand for TiO_2 pigments was estimated to be 2.85 million metric tons while capacity stood at about 3.59 million tons. Capacity expansions continued to move forward, including a 90,000-ton-per-year facility in De Lisle, MS, and an 80,000-ton-per-year facility in Lake Charles, LA. However, environmental regulations in Europe and North America brought pressure to close older pigment plants.

A global oversupply of titanium concentrates caused several mining expansion projects to be delayed. The surplus of supply also caused Australian producers of titanium concentrates to curtail production levels.

A slow global economy and reductions in aerospace markets had a significant negative impact upon demand in the titanium metal industry. World sponge capacity was estimated to be 117,000 tons. While one U.S. producer permanently closed its 10,900-ton-per-

year sponge facility, another U.S. producer proceeded with plans for a 10,000-ton-per-year expansion.

Despite a sluggish economic environment, domestic production and consumption of titanium pigments increased slightly in 1991. Contrary to pigment consumption, consumption of titanium concentrates (ilmenite, slag, rutile, and synthetic rutile) decreased slightly. The United States relied on imports for about three-fourths of its TiO_2 consumption in concentrates. Cuts in defense spending and commercial aerospace combined with inventory reductions caused a significant decrease in domestic production and shipments of sponge metal and mill products. Shipments of titanium metal castings increased significantly.

DOMESTIC DATA COVERAGE

Consumption data for titanium raw materials are developed by the U.S. Bureau of Mines from one voluntary survey of domestic operations. Of the 29 operations canvassed, 28 responded, representing 99.9% of the data in tables 6 and 11. Data for one nonrespondent was estimated based on prior-year consumption levels.

BACKGROUND

Definitions, Grades, and Specifications

Ilmenite is the most abundant titanium mineral, with the chemical formula FeTiO_3 and theoretical composition of

52.7% TiO_2 and 47.3% FeO . However, the term "ilmenite" is also used to include material that has been oxidized and leached during weathering, containing up to 70% TiO_2 , about 25% to 30% iron oxides, and about 5% of oxides of other elements. When the alteration is extreme, the residual material is essentially amorphous to finely crystalline TiO_2 and is called leucoxene.

Rutile is essentially crystalline TiO_2 , and commercial concentrates usually contain about 95% TiO_2 . Synthetic rutile or rutile substitutes are derived from ilmenite by processes involving oxidation and reduction treatments followed by leaching of iron. Synthetic rutile concentrates approach rutile in chemical composition but, being residual leached grains, are porous and composed of very fine crystallites, while natural rutile grains are usually single crystals.

Anatase also is crystalline TiO_2 , but has a different crystal structure than rutile. Anatase is not yet available commercially, but large deposits of anatase-bearing ore in Brazil are being developed.

Commercially available titaniferous slags made by electric furnace smelting of ilmenite with carbon contain 70% to 85% TiO_2 . Slags being produced at the end of 1991 were 80% TiO_2 slag from Sorel, Quebec; 85% TiO_2 slag from Richards Bay, Republic of South Africa; and 75% TiO_2 slag from Tyssedahl, Norway.

Titanium tetrachloride (TiCl_4), the intermediate compound from which titanium metal and chloride-process TiO_2 are manufactured, is a colorless to pale

yellow liquid at room temperature, with a boiling point of 136° C.

Titanium sponge metal is the primary metal form obtained by vapor-phase reduction of $TiCl_4$ with magnesium or sodium metal. It is called sponge because of its appearance and high porosity. Titanium ingot for forging into billet and mill products is obtained by melting sponge in a vacuum-arc furnace, with or without scrap titanium or alloying additions. Specifications for titanium sponge for the National Defense Stockpile (NDS) are given in table 1.

Titanium dioxide pigment is characterized by its purity, refractive index, particle size, and surface properties. The particle size is critical and must be closely controlled within the range of about 0.2 to 0.4 micrometer to develop optimum pigment properties. The superiority of TiO_2 as a white pigment is due mainly to its high refractive index and resulting light-scattering ability, which impart excellent hiding power and brightness. Titanium dioxide pigments are produced as two major types: rutile and anatase. Rutile-type pigment, less reactive with paint vehicles in sunlight than is the anatase type, is preferred for use in outdoor paints. Anatase pigment has a bluer tone than the rutile type, is somewhat softer, and is used mainly in indoor paints and in paper manufacturing.

Specifications for natural rutile for the NDS are shown in table 2. There are no rigid specifications for raw materials to be used as feed for making $TiCl_4$ for metals or pigment manufacture, or for ilmenite or slag to be used in the sulfate pigment process. However, certain impurities such as chromium, columbium, manganese, phosphorus, and vanadium can seriously impair pigment properties, so these impurities are an important consideration in the selection of concentrates for pigment production. Concentrates to be used for making $TiCl_4$ should be low in calcium and magnesium, which form high-boiling-point chlorides that cause trouble in fluid-bed chlorinators. Chemical compositions of typical commercial titanium concentrates

are shown in table 3. (See tables 2 and 3.)

Industry Structure

The titanium industry is moderately integrated from raw materials to semifinished products. The world's largest TiO_2 producer, E. I. du Pont de Nemours & Co. Inc. (Du Pont), obtains ilmenite, rutile, and leucoxene from its own mines in Florida and from various suppliers in other countries, mainly Australia. NL Industries Inc. for many years has supplied ilmenite to its European pigment plants from its mine at Tellnes, Norway. A smelting plant at Tyssedahl, Norway, has been processing part of the Tellnes ilmenite to produce titanium slag for the same market. The Tioxide Group PLC, United Kingdom, owns a 40% share of Westralian Sands Ltd. in Australia. Hanson Industries PLC, United Kingdom, owner of SCM Chemicals Inc., has a 49% interest in Renison Goldfields Consolidated Ltd. (RGC), the major producer of titanium minerals in Australia. A joint venture called Tiwest exists between Minproc Holdings Ltd. and Kerr-McGee Chemical Corp. in Western Australia involving the mining and concentrating of ilmenite, processing of the ilmenite to make synthetic rutile, and manufacture of TiO_2 from the synthetic rutile. Nearly all of the remaining TiO_2 pigment manufacturers buy their raw materials from independent producers of titanium concentrates.

Outside of China and the U.S.S.R., sponge metal producers do not own their own titanium mine. Titanium Metals Corp. of America (TIMET) purchases Australian rutile and manufactures $TiCl_4$, the intermediate compound universally used for commercial production of titanium metal. The other two U.S. titanium metal producers purchase $TiCl_4$ from a TiO_2 pigment manufacturer. Titanium mineral raw materials are purchased also for use in welding rod coatings, chemicals, and fiberglass.

The United States accounts for about 26% of the world's sponge production capacity. Titanium dioxide pigment

output in 1991 came from about 60 separate facilities ranging in annual capacity from a few thousand metric tons to almost 300,000 tons. In 1991, the United States accounted for about 40% of the world's TiO_2 pigment capacity. Significant pigment capacity also exists in France, the Federal Republic of Germany, Japan, and the United Kingdom.

The world's four largest TiO_2 pigment producers are: Du Pont, with plants in the United States and in Mexico; Tioxide, with two domestic plants and facilities in Australia, Canada, France, Italy, Spain, and the Republic of South Africa; SCM Chemicals, with plants in Australia, the United Kingdom, and the United States; and Kronos Inc., with producing plants in Belgium, Canada, the Federal Republic of Germany, and Norway.

U.S. companies, mainly Du Pont, SCM, Kronos, and Kerr-McGee, own or control almost one-half of the world productive capacity for TiO_2 pigments. The remaining portion is owned principally by large chemical firms or groups such as Bayer AG of the Federal Republic of Germany, Ishihara Sangyo Kaisha Ltd. (ISK) of Japan, and Kemira Oy of Finland.

Technology

Exploration.—Hard-rock ilmenite deposits, because of their inherent magnetic properties, are readily amenable to the application of aeromagnetic and ground-magnetic geophysical surveys. These deposits generally respond to such surveys by reflecting abnormally positive magnetic intensities, although in some cases negative magnetic anomalies may result. Once such anomalies are mapped, further exploration may take place in the form of detailed geological observations and ultimately drilling to test the anomalies and delineate the associated ilmenite deposit.

If initial diamond drilling indicates an economic deposit, development drilling proceeds on a set grid pattern of about 200 or 300 feet. Intermediate holes are drilled to fill in major gaps in information on geologic structure or ore

continuations. Drill cores are visually logged and split for chemical assay to determine TiO_2 and iron content.

Sand deposits of titanium minerals are mostly near continental margins where erosion of regional granitic and metamorphic rocks containing ilmenite and rutile has led to accumulation of these minerals in coastal plain sediments. Working and reworking of these sediments by ocean waves on beaches and in streams resulted in various degrees of sand sorting and concentration by particle size, density, and resistance to abrasion. Well-sorted sands are much more likely hosts for ilmenite, rutile, and other heavy minerals than are unsorted sands.

Titanium minerals are dark in color, and their concentration in predominantly quartz sands is often readily visible. Initial discovery has therefore often been made through surface observation. In exploration, hand panning of samples has been a very useful exploration tool.

Some titanium mineral ore bodies are detectable by ground or airborne magnetometer surveys or, if monazite or zircon is present, by low-level radiometric surveys.

Drilling to determine the extent of sand deposits in the first phase of development should be done to a depth of at least 50 feet and preferably 100 feet. The type of drill needed will depend on the nature of the ground, including the presence of clay, hard-pan, roots, stumps, and other organic material, as well as the depth of the water table.

Approximate minimum requirements for an economic sand deposit of titanium minerals include reserves of 300,000 to 1 million tons of TiO_2 content in rutile or ilmenite and heavy-mineral content in the ore of 1% to 5%, depending on the mix of ilmenite, rutile, and other valuable minerals.

Mining and Concentration.—For mining sand deposits of titanium minerals, a dredge is usually used. This may be bucket-ladder type but is more likely to be suction type. The dredge floats in its own pond, digging forward and stacking tailings aft. Rough concentration, the separation of heavy

minerals from the lighter quartz-feldspar-mica fraction, is usually accomplished by wet-gravity methods. The Humphreys spiral has been standard for this separation since its introduction about 1940, but pinched-slucice separators of various designs have also been used. In Australia, the Reichert cone concentrator, which operates on the pinched-slucice principle, has been successful for large-tonnage operations. Flotation has also been used to some degree. For separating the minerals from stream-type deposits, jigs are usually chosen because they are the concentrating device least sensitive to extreme grain-size variation.

The final wet-mill concentrate is dried, usually in a rotary kiln, prior to further treatment. The subsequent flowsheet depends on the mineral assemblage to be treated. Ilmenite and rutile are usually removed together by electrostatic separation. The ilmenite-rutile conductor fraction of dried wet-mill concentrate is then subjected to high-intensity magnetic separation, yielding a final ilmenite product. The rutile fraction is further cleaned by screening and additional electrostatic separation. Zircon and monazite products are recovered from the nonconductor fraction of the wet-mill concentrate by a combination of gravity, electrostatic, and high-intensity magnetic separation.

Ilmenite is also mined from two hard-rock deposits, one in Canada and one in Norway. The ore bodies are massive, and open pit mining is practiced.

At Tellnes, Norway, the ore is crushed, ground, and subjected to wet-magnetic separation to recover magnetite. An ilmenite concentrate containing about 44.5% TiO_2 is recovered by flotation of the nonmagnetic portion, as was formerly done at the MacIntyre Development, Tahawus, NY, where ilmenite mining ceased in 1982.

At Allard Lake, Quebec, ore at 32% to 36% TiO_2 is shipped from the mine to the beneficiation plant at Sorel, Quebec; some of the ore is shipped to steel companies as a substitute for fluorspar flux. For upgrading to slag, the ore is

crushed and ground, concentrated by gravity methods, roasted to remove sulfur, mixed with a reducing agent, and smelted in an electric arc furnace. A high-purity pig iron is produced. The titanium is concentrated in the slag, known as Sorelslag, which contains 80% TiO_2 . Since the iron content of the slag is low, its use reduces the quantity of iron sulfate in the liquid effluent of sulfate process pigment plants. Because of its relatively high content of magnesium and calcium, which cause operating problems during chlorination, Sorelslag is not used to make TiCl_4 .

At Richards Bay, Republic of South Africa, both rutile and ilmenite are produced from heavy-mineral sand deposits. The ilmenite, containing about 50% TiO_2 , is relatively low in magnesium and calcium and is smelted with carbon in an electric furnace to produce an 85% TiO_2 slag. Because of its low content of the above impurities, the Richards Bay (RB) slag is acceptable for manufacturing TiCl_4 and is also a feed material for the sulfate pigment process.

Materials made from ilmenite that have a TiO_2 content approaching that of natural rutile are known as synthetic rutile or beneficiated ilmenite. Processes to produce rutile substitutes from ilmenite fall into three general classes: those in which the iron is completely reduced to metal and separated from the reaction mass either physically or chemically, those in which iron is reduced to the ferrous state and chemically leached away from the titanium, and those in which the ilmenite is selectively chlorinated to remove iron and other impurities. The RB slag described in the previous section may also be regarded as a rutile substitute because of its high grade (85% TiO_2) and suitability for the manufacture of TiCl_4 .

Pigment Production.—Titanium dioxide pigment is produced commercially by two methods that require different raw materials. In the sulfate process, ilmenite or titanium slag is reacted with sulfuric acid, a portion of the iron sulfate formed may be crystallized and removed, and titanium hydroxide is precipitated by hydrolysis,

filtered, and calcined. In the chloride process, rutile is converted to $TiCl_4$ by chlorination at 850° to 950° C in the presence of petroleum coke. All U.S. commercial chloride-process plants use fluid-bed chlorinators, although static-bed systems can be used for this purpose.

Titanium tetrachloride so prepared may be used either in making pigment, or with additional purification, for reduction to metal. In making pigment, the $TiCl_4$ is oxidized with air or oxygen at about $1,000^\circ$ C, and the resulting fine-size TiO_2 is calcined at 500° to 600° C to remove residual chlorine and any hydrochloric acid that may have formed in the reaction. Aluminum chloride is added to the $TiCl_4$ to ensure that virtually all of the titanium is oxidized in the rutile crystalline form.

Recoveries of TiO_2 in pigment are approximately 90% and 80% to 85% for chloride process and sulfate process plants, respectively.

Metal Production.—Feed materials needed for metal production are the same as those for chloride-process pigment because formation of $TiCl_4$ is required in both cases. Rutile and rutile substitutes are the only titanium raw materials used for metal production in the market economy countries.

Titanium sponge is produced by reducing $TiCl_4$ with sodium or magnesium under an inert atmosphere at temperatures up to $1,040^\circ$ C. Residual chlorides are removed by vacuum distillation, inert gas sweep, or after cooling and crushing, by leaching in very dilute acid. The sponge is compacted, usually with some scrap and alloying additions, and made into ingot by two or more successive vacuum-arc melting operations.

Recycling.—Scrap titanium generally accounts for 40% to 50% of ingot production. Scrap is generated by producers of ingot and mill products and by consumers of mill products in fabricating finished products or components. It is estimated that up to 75% of titanium ingot metal becomes

scrap during processing to finished parts. However, the proportion of scrap is gradually being lowered because of increased use of castings and other near net-shape technologies.

Clean and well-segregated scrap, processed to remove impurities, is blended with sponge metal and alloying constituents and remelted to ingot. Remelting is mainly by vacuum-arc consumable-electrode processing. Electron-beam and plasma-arc cold-hearth melting is also used, especially for chips and turnings. Cold-hearth melting is very effective in ensuring removal of high-density inclusions, such as tungsten carbide tool particles, which settle out in the hearth area during melting. A substantial quantity of titanium scrap, particularly unprocessed turnings, is consumed directly or in making ferrotitanium for use in steel and other alloys.

Economic Factors

Prices.—The price of rutile pigments and titanium sponge in constant dollars decreased 20% and 14%, respectively, from 1969 through 1972, as shown in table 4. Reflecting a sharp increase in pigment demand, the constant dollar price rose 32% in 1974. The pigment price did not surpass that level until 1989, following 6 consecutive years of record-high demand. An economic downturn in 1990 and 1991, coupled with new capacity, caused a drop in pigment prices. The titanium sponge price reached a record high in 1980 because of unprecedented demand for commercial aircraft, then dropped sharply in 1982 and 1983 following a severe downturn in the commercial aircraft market. Although sponge consumption was near record-high levels in 1989, the constant dollar price was several percent below the moderate levels of 1975-77. The decline in sponge consumption in 1990 and 1991 was reflected by a decrease in price. Published prices of titanium concentrates and products in 1990-91 are listed in table 15. (See table 4.)

Costs.—Construction cost of a 110,000-ton-per-year synthetic rutile plant completed in 1977 at Mobile, AL, was reportedly \$53 million, or about \$480 per annual ton of product.

The cost of constructing a new 82,000-ton-per-year chloride-process pigment plant is about \$2,500 per ton of annual capacity. Sulfate-process plants, including neutralization facilities, were said to cost considerably more. The operating costs for chloride plants, which may be operated continuously and are more easily automated, reportedly were as much as 30% lower than those for sulfate plants. The cost of finishing titanium pigment for marketing is about the same for both processes and composes a significant portion of the total costs. Mineral raw material costs in the sulfate process are appreciably lower than those in chloride-process plants that use rutile as feed material.

Plant costs for producing titanium sponge are very high. The estimated cost per annual ton of capacity is about \$12,000 to \$15,000. Raw material costs for producing titanium sponge are about the same, whether reduction is with sodium or magnesium, and the selection of one reductant over the other depends on local market economics.

Tariffs.—The duties shown in table 5 reflect results of the Tokyo Round of Multilateral Trade Negotiations completed in 1979 under which tariffs on many items were reduced in several stages over the period January 1, 1980, to January 1, 1987. (See table 5.)

Depletion Provisions.—The depletion allowance for ilmenite and rutile is 22% when mined from domestic deposits and 14% from foreign deposits.

Operating Factors

Environmental Requirements.—Heavy-mineral sand mining presents few serious environmental hazards. The land is restored by returning the bulk of the sand after removal of the ore minerals and may even be improved in low, flat

areas. Dune areas can be left in nearly their original form, and the sand can be stabilized by seeding and replanting.

The major environmental problem in the titanium industry is the disposal of wastes from pigment-producing processes that use ilmenite, generating up to 3.5 tons of waste per ton of product. Solutions to this problem required the development of methods to neutralize and control the effluent now produced by the sulfate pigment process, mainly a solution of waste sulfuric acid and ferrous sulfate heptahydrate. Deep well disposal has been used for waste ferric chloride produced when ilmenite is used to make $TiCl_4$. In processes for making synthetic rutile, the effluent solutions are treated to regenerate the original leaching agent, such as hydrochloric acid, which is recycled, and to form useful byproducts such as sodium sulfate, ammonium sulfate, and iron oxide. In sulfate-process technology, there is a strong trend away from disposal of waste materials in streams or in the ocean. Both U.S. sulfate-process producers now are using waste treatment plants that neutralize acid effluent with limestone and lime and produce gypsum and iron oxide byproducts. Such neutralization processes add about \$100 per ton to the cost of the TiO_2 pigment product. The sale of all byproducts recovers only a small fraction of this cost.

In 1989, the Environmental Protection Agency (EPA) published a newly revised interpretation of the Bevill exclusion, which exempts mineral processing wastes from regulation under subtitle C of the Resource Conservation and Recovery Act (RCRA). EPA's revised interpretation addressed the definition of mineral processing and established high-volume and low-hazard criteria for waste streams to be retained within the Bevill exclusion.¹ Subsequent proposed rulemaking, published in 1990, applied this revised interpretation to 20 waste streams that were conditionally retained in the Bevill exclusion.² In the TiO_2 - $TiCl_4$ sector, chloride processing waste solids were retained, passing both the high-volume and low-hazard criteria. However, other waste streams in this

sector were not retained: sulfate process waste acids, having failed to pass the low-hazard criterion; and sulfate process waste solids, chloride process waste acids, and titanium leach liquor, which all failed the high-volume criterion. EPA estimated compliance costs for the sulfate process portion of the titanium dioxide sector to average 0.8% of the value of shipments for the affected facilities.

Toxicity.—Titanium is a nontoxic material, as demonstrated by the use of TiO_2 in cosmetics and the use of titanium for making pacemakers and other implant devices for humans. However, some titanium compounds can be hazardous; for example, $TiCl_4$, which reacts violently with water or moisture in the air, forming TiO_2 and hydrochloric acid.

Energy Requirements.—According to a 1975 study for the U.S. Bureau of Mines, energy requirements for alluvial mine production are about 5.1 million British thermal units (Btu's) per ton of TiO_2 in concentrate. Production of pigment requires about 75 to 112 million Btu's per ton of TiO_2 , depending on the process and feed material used. Titanium sponge production uses from 408 to 466 million Btu's per ton of metal, of which about 248 to 270 million Btu's is required to regenerate the reductant and chlorine. The conversion of sponge metal to titanium ingot requires an additional 46 million to 57 million Btu's per ton of titanium ingot.³

ANNUAL REVIEW

Legislation and Government Programs

In May, the EPA made a final determination that none of the 20 wastes that were conditionally excluded from regulation under subtitle C of RCRA would be regulated as hazardous. The wastes, including waste solids from titanium tetrachloride processing, may be included in a special subtitle D regulatory process being developed for nonhazardous mining extraction and beneficiation wastes. (See table 6.)

Strategic Considerations

Security of Supply.—Although imports supply a very large proportion of domestic consumption of titanium concentrates, these imports come predominantly from Australia and Canada, which have historically been reliable and politically stable suppliers.

Import reliance, defined as imports less exports plus adjustments for inventory changes, may be used as a measure of dependence on foreign sources of supply. Expressed as a percentage of consumption, import reliance for ilmenite, including high TiO_2 slag made from ilmenite, was 35% in 1980 but increased to about 80% in the 1982-84 period because of cessation of production at two U.S. ilmenite mines. Ilmenite import reliance through 1991 generally has been in the 70% to 80% range. Import reliance for rutile declined from about 90% in 1980 to about 60% in 1983, and in later years it has remained in the 60% to 70% range because of increased production of synthetic rutile. However, this decline was at the expense of increased import reliance for ilmenite, because the domestic synthetic rutile was made from Australian ilmenite.

Dependence on foreign rutile sources could be eased or eliminated in an emergency in two ways, using current commercial processing methods: (1) Synthetic rutile could be made from domestic ilmenite now being mined in Florida or ilmenite that could be mined from other deposits, such as the Tennessee ilmenite sand deposits. (2) Titanium tetrachloride for metal production could be made directly from ilmenite, as is done by Du Pont for TiO_2 pigment manufacture.

Another possible solution to this problem is the development of new processes that utilize domestic ilmenite and perovskite that contain too much calcium and magnesium to be used directly for making $TiCl_4$. Availability of such processes would encourage production of domestic ilmenite, which fell from about 450,000 tons of contained TiO_2 in 1975 to about 165,000 tons of TiO_2 in 1982. In 1991, ilmenite mine

production capacity was about 200,000 tons per year of contained TiO_2 .

Import reliance for titanium sponge as a percentage of consumption has ranged from 0% to 16% between 1980 and 1991, and the United States was a net exporter in 1990. Titanium concentrates currently used to make $TiCl_4$ for metal production are mostly imported rutile and synthetic rutile, but domestic concentrates could be used for this purpose in an emergency, possibly at higher cost.

Stockpile.—Rutile and titanium sponge metal are included in the list of strategic and critical materials for stockpiling purposes. Titanium sponge has been acquired periodically for the NDS from domestic producers and from producers in Japan and the United Kingdom. Rutile for the NDS was acquired mainly in the early sixties from Australia.

The Government's NDS goal for titanium sponge metal remained at 176,901 tons. The NDS inventory in December contained 23,555 tons of specification metal and 9,857 tons of nonspecification material. The NDS goal for rutile was unchanged at 96,162 tons. The total rutile stockpile inventory at yearend was 35,549 tons, including 51 tons of nonspecification material.

Issues

U.S. Ore Supply.—Although the United States has large reserves of titanium in the form of ilmenite, nearly all of U.S. titanium sponge production has been derived from imported rutile and synthetic rutile. This heavy reliance on foreign concentrates has developed because most producers of $TiCl_4$, the intermediate compound used to make titanium and a large part of the world's TiO_2 pigment, prefer rutile or synthetic rutile over ilmenite as plant feed material. Possible ways of better utilizing U.S. ilmenite resources and reducing U.S. dependence on foreign sources of titanium concentrates are discussed previously.

Fluctuations in Metal Demand.—A major problem affecting the titanium industry is the wide fluctuations in demand caused by changes in requirements for both military and commercial aircraft programs. Titanium sponge producers have repeatedly increased capacity in response to anticipated demand and have then been left with excess capacity when those programs were canceled or cut back. It has been suggested that the aerospace industry could help stabilize demand and match supply to demand by better long-range planning and forecasting of their requirements and greater use of multiyear contracts. In the event that additional capacity is needed quickly in a national emergency, incentives such as loan guarantees and a guaranteed floor price for purchases from new capacity could be used, as authorized under the Defense Production Act. Further diversification of titanium into nonaerospace industrial applications would also help stabilize titanium demand.

Production

Concentrates.—U.S. producers of ilmenite in 1991 were Associated Minerals (USA) Ltd. Inc. (AMU) at Green Cove Springs, FL; Du Pont at Starke and Highland, FL, both from mineral sands deposits; P. W. Gillibrand Co., Simi Valley, CA, as a coproduct of its rock, sand, and gravel operations; and Nord Ilmenite Corp., Jackson, NJ, from a previously mined mineral sands deposit. AMU was the only U.S. producer of natural rutile. Kerr-McGee was the sole domestic producer of synthetic rutile, at Mobile, AL. Interest continued in exploration and potential development of mineral sands in North Carolina and Virginia. Several companies have conducted detailed drilling and feasibility studies and mining at one or more of these deposits could begin by 1993.

Du Pont had previously announced plans to begin mining mineral sands at the company's new operation in Maxville, FL, in 1992. However, startup for this

project has been delayed until sometime in 1993.

Ferrotitanium.—Ferrotitanium was produced by Galt Alloys Inc., Canton, OH; HTP Co., Sharon, PA; and Shieldalloy Metallurgical Corp., Newfield, NJ. Two grades were produced—a 40%- and a 70%-titanium grade.

Metal.—At yearend 1991, RMI Titanium Co. made plans to permanently close its sodium and titanium metal reduction facilities at Ashtabula, OH. In October, RMI had made concessionary wage and benefit proposals to the local unions that represented the employees at Ashtabula. However, no agreements could be reached, and notices were given to the 369 employees at the plant. Pending the termination of its sponge production capability, RMI entered into two long-term purchase agreements with domestic and foreign sources. The expected closure would eliminate 10,900 tons per year of sponge capacity as well as 140,000 tons of sodium chloride and 22,700 tons of sodium and sodium hypochlorite capacity.

Oregon Metallurgical Corp. (Ormet) entered into an agreement with Oregon Steel whereby Oregon Steel would roll titanium plate for Ormet at its facility in Portland, OR. Ormet had shipped its slabs to a rolling mill in Pennsylvania. The move was expected to significantly reduce lead time and transportation costs.

Ormet brought on-line a vacuum-creep flattener capable of producing high-grade titanium plate nearly as thin as sheet. The new system avoided the use of a forge press, which introduces waviness and bowing when used to produce thin plate. Most of the design and construction was done in-house. The flattener was designed to process up to 6 tons of plate per run with a projected 40 runs per year. The finished plate was reported to have tolerances of 0.005 to 0.010 inch.⁴

Howmet announced plans to consolidate its machining and production activities. The plans included closing its

machining operations at its Whitehall, CT, facility and merging these operations into its Plymouth, MI, facility. In addition, the melt activities from Plymouth would be integrated into Howmet's facility in Dover, NJ.

TIMET held a groundbreaking ceremony to mark the construction of a vacuum-distilled titanium sponge plant in Henderson, NV. In exchange for a possible 25% equity interest in TIMET, Union Titanium Sponge, a Japanese consortium, was expected to provide the majority of the financing for the project. The members of Union Titanium included Toho Titanium Co., Nippon Mining Co., Nippon Steel Corp., and Mitsui Co. Technology for the new furnace was being provided by Toho, and the construction was being conducted by Jacobs Engineering Co. The new facility was expected to produce 10,000 tons per year of sponge. TIMET's capacity in 1991 was 12,700 tons per year. When the new facility is completed, TIMET planned to decommission 8,200 tons of old capacity leaving 14,500 tons per year of capacity. TIMET expected the new capacity to be more cost efficient and yield a higher purity product.

NKK Corp. sold its 40% stake in International Light Metals to Martin Marietta Corp. The sale marks NKK's withdrawal from its 6-year joint venture with Martin Marietta.

In response to a need identified by the jet engine industry, Axel Johnson Metals Inc. installed a state-of-the-art electron beam hearth furnace capable of processing up to 4,500 tons of titanium ingot annually. The furnace was reported to be primarily for commercial aerospace use.

In November, Teledyne Allvac commissioned a fully automated bar and rod mill at Richburg, SC. The new mill was supplied with billet from Teledyne's nearby melting and forging facilities at Monroe, SC.⁵ (See tables 7 and 8.)

Titanium Dioxide Pigments.—U.S. production of TiO₂ pigments increased in 1991. Producing plants operated at 87% of their 1,135,000 tons per year of capacity.

Kronos Inc. began trial operations of a 80,000-ton-per-year chloride-based plant in Lake Charles, LA. The plant was expected to be commissioned in 1992.

Du Pont started a new line at its De Lisle, MS, titanium pigment plant. The new line adds 90,000 metric tons per year of new capacity based on the chloride process. (See tables 9 and 10.)

Consumption and Uses

Concentrates.—Total U.S. consumption of TiO₂ in concentrates decreased about 2% from the 1990 level. This decline was mainly attributed to a slowing economy. Although consumption in ilmenite increased by 7%, consumption in slag and rutile decreased by 7% and 3%, respectively. Pigments constituted 95% of total TiO₂ consumption by end use. (See table 11.)

Ferrotitanium.—Reported consumption of titanium in the form of ferrotitanium and scrap in steel and other alloys decreased by about 17%.

Metal.—Net shipments of mill products fell by about 35%, and sponge production also decreased by 41%. Consumption of scrap for remelting supplied a calculated 45.7% of ingot feedstock compared with 40.7% in 1990. Castings shipments increased by 26%.

Mill product shipments by product type were forging and extrusion billet, 48%; sheet, strip, plate, extrusions, and other, 38%; and rod and bar, 14%.

Estimated U.S. mill product usage, by application, was as follows: commercial aircraft, 41%; military aerospace, 37%; chemical industry, including pulp and paper, 10%; powerplant condensers, 4%; naval and other marine uses, 3%; medical implants, 1%; and other uses, mainly oil drilling, flue gas desulfurization, and automotive, 4%.

Current use of titanium in large commercial aircraft represents about 6% of aircraft empty weight. Titanium is utilized where high-strength toughness, heat resistance, and high structural efficiency are required. Typical aircraft

uses are for structural forgings, such as the landing gear beam in the Boeing 757; wing skins for the F-14 and F-15 fighter aircraft; rotor parts for helicopter systems; B-1B fracture-critical forgings and wing support sections; and rotor discs and compressor blades on various engines.

Future trends in consumption point toward a higher percentage of titanium in commercial aircraft. Boeing Co. forecasted that 9% of the new 777 airframe would probably be constructed of titanium.⁶ The forecast is significantly higher than the average titanium percentage used in most commercial aircraft to date. Specific areas where titanium has been chosen for this aircraft include the fuselage, wing and landing gear structures, flap tracks, cockpit windshield frames, environmental and deicing ducting, and portions in and under the galleys.

Major nonaerospace industrial uses are mainly those requiring superior resistance to corrosion.

Pigment.—Apparent domestic consumption of TiO₂ pigments was about 958,000 tons, about 4% more than that in 1990. (See tables 12 and 13.)

Stocks

The TiO₂ content of inventories of ilmenite decreased by 26% while inventories of rutile increased 22%. Overall TiO₂ content of concentrate stocks decreased by 3%. Stocks of TiO₂ pigment increased by 17% to 72,000 tons. (See table 14.)

Markets and Prices

Published prices of ilmenite and titanium slag concentrates fell slightly during 1991. Meanwhile, prices for rutile rose moderately. Titanium dioxide pigment prices decreased slightly during 1991. (See table 15.)

Published prices of titanium sponge prices and mill products were unchanged during most of the year. However, according to industry sources, transaction

prices for metal products decreased significantly. Owing to a lack of demand, scrap metal prices also fell significantly during the year.

Foreign Trade

Imports of titanium raw materials increased by 11% from those in 1990. On the basis of TiO_2 content, principal import sources for raw materials were the Republic of South Africa, 46%; Australia, 33%; Sierra Leone, 11%; and Canada, 9%. In 1991, the Republic of South Africa surpassed Australia as the leading import source for concentrates. (See tables 16, 17, 18, and 19.)

World Review

Capacity.—The data in table 20 are rated capacities for mines and beneficiation plants, sponge metal facilities, and TiO_2 pigment plants as of December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time at a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and temporarily closed facilities that, in the opinion of the author, can be brought into production within a short period of time and with minimum capital expenditure.

Mine and mill capacity for the production of titanium concentrates, metal production plant capacity, and TiO_2 pigment plant capacity are generally based on close to 365 days per year of operation, 3 shifts per day. Capacity figures are based on information obtained from the producing companies, from news items, and from U.S. Bureau of Mines estimates. (See table 20.)

Reserves.—U.S. and world reserves and reserve base data for titanium are shown in tables 21 and 22. U.S. reserves of 7.8 million tons of TiO_2 in ilmenite and 300,000 tons of TiO_2 in rutile occur

mainly in ancient beach sand deposits in Florida. Ilmenite concentrates from the U.S. sand deposits contain about 60% to 65% TiO_2 , while those from rock deposits contain 45% to 50% TiO_2 . The U.S. reserve base of 34.7 million tons of TiO_2 occurs as 23.5 million tons in ilmenite, 9.8 million tons in perovskite ($CaTiO_3$), and 1.4 million tons in rutile.

Other U.S. resources include additional rock deposits of ilmenite in California, Minnesota, New York, and Wyoming and sand deposits of ilmenite and/or rutile in Georgia, Idaho, New Jersey, North Carolina, Oregon, and South Carolina, as well as large quantities of accessory rutile in porphyry copper ores and mill tailings.

The U.S. Bureau of Mines is compiling a computerized file of worldwide mineral deposit data called the Minerals Availability System (MAS). When fully developed, MAS will provide a means of analyzing supply positions relative to available reserves, mineral-related land use issues, environmental issues, and a variety of problems associated with the mining, processing, and transporting of titanium and other commodities. Most of the resource data in tables 21 and 22 were derived from MAS reports.

Major titanium reserves in the United States are owned by Du Pont and AMU in Florida. Reserves in Australia are held mainly by Associated Minerals Consolidated Ltd. (AMC), a subsidiary of RGC; Consolidated Rutile Ltd.; Westralian Sands Ltd.; and Cable Sands Ltd. Reserves at Allard Lake, Quebec, Canada, are held by QIT-Fer et Titane Inc. (QIT), now a subsidiary of RTZ Corp. PLC. QIT also has a 50% interest in Richards Bay mineral sands deposits in the Republic of South Africa. Major deposits in Brazil, India, and Sri Lanka are held by the respective governments. NL Industries controls Titania A/S, owner of the large hard-rock deposit at Tellnes, Norway. (See tables 21 and 22.)

U.S. reported consumption of titanium dioxide in concentrates in 1991 was 1,086,000 tons. At this annual consumption rate, U.S. reserves of 8,000,000 tons would be sufficient for

only about 7 years, without imports. However, with the current level of import reliance at about 60% of reported consumption, these reserves would provide nearly a 20-year supply of titanium. The U.S. reserve base of 35 million tons TiO_2 content is equivalent to more than 30 times the 1991 domestic consumption level.

World production of TiO_2 in concentrates decreased slightly in 1991, in line with the slight decrease in world demand. However, production capacity for TiO_2 in concentrates increased by about 5%, and TiO_2 pigment production capacity increased by about 7% in 1991. Because of increased environmental regulations, particularly in Europe, regarding disposal of waste acid from sulfate-process TiO_2 plants, several producers have closed or invested in additional acid recycling equipment to reduce or eliminate acid disposal. (See table 23.)

Australia.—SCM Chemicals closed its 34,000-ton-per-year titanium pigment plant at Bunbury, Western Australia. The plant had been based on the sulfate process. In 1989, as a precursor to the closure, SCM had constructed a 70,000-ton-per-year plant based on the chloride process. In 1991, SCM produced pigment by both chloride- and sulfate-based technologies, and its global capacity was estimated to be 392,300 tons.

In Australia, estimated production of both ilmenite and rutile declined by about 15% to 20% as a result of a decrease in world demand for TiO_2 pigments. Cutbacks made by all the Australian producers, except the newly commissioned TiWest Joint Venture, contributed to the decrease in production.

AMC Mineral Sands Div. of RGC closed its Eneabba North mining site in early 1991, and production of sulfate-grade ilmenite at Capel was reduced to compensate for the closure of SCM's sulfate-route pigment plant at Bunbury. AMC's Eneabba West operation was providing additional mineral sands output, but production did not completely replace the lost production from Eneabba North.

The company also planned to close one of its 130,000-ton-per-year synthetic rutile kilns at Narngulu for 6 months.

Westralian Sands' Yoganup Extended mine remained closed since August 1990, and production from the company's Capel operations has decreased. Consolidated Rutile's operations in North Stradbroke Island, Queensland, also were closed during part of the year.

The new TiWest Joint Venture operation in Cooljarloo, which began producing ilmenite in 1990, started synthetic rutile production in January 1991. Production capacity at the synthetic rutile plant was reported to be 68,000 tons per year. Minproc Holdings Ltd. owned 50% of the TiWest Joint Venture.⁷

Brazil.—Owing to technical problems with the anatase concentrate and titanium $TiCl_4$, Companhia Vale do Rio Doce (CVRD) shut down its 50-ton-per-year titanium sponge pilot plant. CVRD was also reported to have signed an agreement with Du Pont to restudy technical and economic issues in the production process. Du Pont received Governmental approval for a 60,000-ton-per-year plant to produce pigment from anatase ore based on sulfate technology. At yearend, Du Pont was already close to completion of a 15,000-ton-per-year finishing plant at Uberaba, Minas Gerais State.

Cameroon.—Consolidated Rutile signed a joint-venture agreement with an arm of the Cameroon Government to mine a mineral sands deposit near Akonolinga, Cameroon. Consolidated Rutile reportedly plans to produce 50 tons of rutile annually for a 10-year period, although no startup date was established.

Canada.—QIT's 80%- TiO_2 slag production capacity reportedly was cut to 75% at its plant in Sorel during the latter half of the year. This plant supplied feedstock to sulfate-process TiO_2 pigment plants, and the production cutback resulted from a drop in pigment production.

Tioxide announced that it would construct a new chloride-process TiO_2 pigment plant at Becancour, Quebec. The new plant was expected to replace sulfate-based production at Tracy, Quebec. Completion of the new plant was scheduled for 1994, and the plant would use Tioxide's energy-efficient Independent Chlorination and Oxidation (ICON) process. Capacity at the plant was anticipated to be 60,000 tons per year of semiprocessed material. When completed, the Becancour facility would ship the semifinished product to the Tracy plant for final processing, and the sulfate-based pigment capacity at Tracy would be shut down.

France.—Tioxide began a program at its Calais, France, facility to improve environmental standards. The Calais project recycled acid within the sulfate-based plant. The process reconcentrated acid liquid effluent for use in pigment production and converted metallic sulfates into an ash suitable for landfill.⁸

India.—A commercial-scale titanium sponge facility was under construction at Tuticorin in Tamil Nadu. The facility was an initiative of the Indian Atomic Energy Commission and was anticipated to be capable of producing 1,000 tons per year when completed. In addition, a facility was expected to be constructed that would produce magnesium from seawater for the metal reduction plant.⁹

Japan.—According to preliminary Japanese Titanium Association statistics, during 1991, demand for sponge in Japan was 35% less than that of the previous year. Production at all three sponge producers, Showa Titanium Co. Ltd., Toho Titanium, and Osaka Titanium Co., Ltd., was reduced during the fourth quarter because of poor business conditions in both Japan and the United States.

Toho Titanium began to renovate its sponge facilities at Chigasaki in Kanagawa Prefecture. When completed, 7.4-ton furnaces would replace the existing 1.6-ton furnaces. The

renovations were not expected to change the facility's total capacity of 10,800 tons per year.

Osaka Titanium completed streamlining renovations of its titanium sponge plant. Sponge capacity at the plant was reported to be 15,000 tons per year.¹⁰ Osaka was also reported to be proceeding with plans to construct an additional furnace at its Amagasaki facility to increase ingot output to 4,680 tons per year. The new furnace was expected to be commissioned in 1992.¹¹

Korea, Republic of.—Du Pont received approval from the South Korean Government for a titanium pigment plant in Ulsan. The facility was reported to be a joint venture with Han Yang Chemical. When completed, the plant was anticipated to have a capacity of about 60,000 tons per year. The plant was expected to be completed in 1994.

Malaysia.—Tioxide made plans to commission a new pigment facility in 1992 at Telok Kalong in Terengganu. The new 50,000-ton-per-year facility was based on sulfate technology.

Mexico.—Du Pont was reported to be expanding capacity to 90,000 tons per year at its facility at Tampico, Mexico. The expansion was expected to be completed in 1992.

Netherlands.—American Cyanamid sold its 50% equity ownership in TDF Tiofine to Billiton Nederland BV. The sale resulted in Biliton's sole ownership of the Netherlands-based TiO_2 pigment producer.¹²

Saudi Arabia.—Late in the year, Crystal Pigment Co., a joint venture between Kerr-McGee (25%) and several Saudi Arabian investors, opened a 50,000-ton-per-year chloride-process pigment facility at Yanbu, Saudi Arabia. Technology at the plant was based on an ICI chloride process.

Sierra Leone.—Hazcare Pty. Ltd., a subsidiary of Pioneer Resources, signed a

prospecting license and Memorandum of Understanding covering the Rotifunk and Sembehun rutile, ilmenite, and zircon deposits. Inferred resources were reported to be 1,410,000 tons of rutile, 2,180,000 tons of ilmenite, and 128,000 tons of zircon. A program was scheduled to upgrade the resource to a measured category.¹³

South Africa, Republic of.—Shell SA and Rhombus Exploration (Rhoex) reportedly have signed an agreement to conduct a feasibility study on a mineral sands deposit in the Empageni district of Natal. Rhoex was responsible for conducting the geological work on the project.¹⁴ Meanwhile, Richards Bay Minerals increased its TiO₂ slag capacity to 1,000,000 tons per year by commissioning its fourth slag smelter.

Taiwan.—Du Pont continued construction of a 60,000-ton-per-year TiO₂ plant. The plant was expected to be commissioned in the fourth quarter of 1993.

United Kingdom.—In response to recently enacted environmental restrictions, SCM reduced capacity at its Stallingborough, England, TiO₂ pigment plant. The reduction eliminated pigment production based on sulfate process and brought the plant's capacity down to 95,000 tons per year.

Tioxide began a program at its Grimsby plant to improve environmental standards. The improvements include a neutralization process for the plant's effluent. The process, which has been used in Malaysia, would generate two grades of gypsum for plasterboard manufacture and landfill.¹⁵

U.S.S.R.—According to press reports, one of the four major sponge facilities in the former U.S.S.R. was forced to halt production after running out of raw materials. Because of a lack of hard currency, the Kamenogorsk plant in Kazakhstan was unable to purchase the raw materials to continue production.

The facility was reported to have an annual capacity of 20,000 tons per year.

Two TiO₂ pigment producers in the former U.S.S.R. were expected to increase their production levels to meet the growing demand in the country. Lakokraska planned to increase production at its Armianisk sulfate-process plant from 80,000 tons per year to 120,000 tons per year by 1992. Environmental problems with the plant's effluent would have to be solved before the local government will grant permission for the expansion. In 1991, production in the U.S.S.R. was estimated to be 120,000 tons per year, and demand was estimated to be 200,000 tons per year. Demand was expected to increase to 400,000 tons per year by 2000.

Current Research

Textron Specialty Metals, developer of a composite material made from a continuous silicon carbide filament embedded in titanium, was awarded an \$8.6 million contract to fabricate structural test components and develop material technology for the National Aerospace Plane (NASP). The NASP was conceived as a single stage to orbit craft without a supplemental launch vehicle. When completed, the NASP would travel at hypersonic speeds and be capable of taking off and landing on a runway. Since the silicon carbide-titanium material developed by Textron was determined to be capable of withstanding extremely high temperatures (1,600° F), the material was considered extremely suitable for the NASP application. The NASP program was being jointly funded by the Air Force and National Air and Space Administration.

In an effort to reduce U.S. dependence on imports of titanium, the U.S. Bureau of Mines investigated the recovery of titanium from perovskite (CaTiO₃). The untapped U.S. resource of perovskite includes an estimated 9.8 million tons in Colorado. The process being investigated is an acid sulfation method, which would extract about 97% of the titanium and columbium as well as 70% to 90% of rare earths from perovskite concentrates.

The process may be an economically viable method to produce pigment-grade TiO₂.

OUTLOOK

According to industry reports, consumption of titanium pigment in North America is expected to grow at 2.1% annually to 1995. Meanwhile, demand in Western Europe is expected to grow at 2.6% per year. In Asia and Oceania, demand is predicted to increase by 4.3% to 1995. Although producers added 177,000 tons of annual pigment capacity from 1985 to 1990 and are scheduled to add 295,000 tons by 1995, further capacity expansions are expected to be required to meet demand. Future expansions are anticipated in areas with relatively high demand such as Asia, Latin America, and the Middle East.¹⁶

The outlook for the titanium metal industry is unclear. Cuts in military aerospace spending will continue to affect the industry for some time. However, the titanium content in commercial aircraft is expected to grow, and titanium metal producers are aggressively pursuing nonaerospace markets. An ample supply of titanium metal should be available to meet domestic and global needs for several years.

The development of newly discovered deposits and the continued development of processing technologies are expected to ensure an adequate supply of titanium concentrates for several years. Growth in consumption of concentrates is dependent on consumption by titanium pigments.

¹Federal Register. Mining Waste Exclusion: Final Rule (Environ. Protection Agency). V. 54, No 169, Sept. 1, 1989, pp. 36592-36642.

²_____. Mining Waste Exclusion: Section 3010 Notification for Mineral Processing Facilities; Designated Facility Definition; standards Applicable to Generators of Hazardous Waste; Final Rule (Environ. Protection Agency). V. 55, No. 15, Jan. 23, 1990, pp. 2322-2354.

³Battelle Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing. Phase 5—Energy Data and Flow Sheets, Intermediate Priority Commodities. Sept. 16, 1975, pp. 172-202. Nat. Tech. Inf. Service, Springfield, VA, PB 246-357.

⁴American Metal Market. Thinner Titanium Plate Rolled. V. 99, No. 153, Aug. 12, 1991, pp. 4, 14.

³Light Metal Age. State-of-the-Art Bar and Rod Rolling Mill for Titanium and Other Special Metal Products. V. 49, No. 11, Dec. 1991, pp. 21-23.

⁴American Metal Market. Boeing Bullish on 777 Titanium Use. V. 99, No. 220, Nov. 19, 1991, pp. 1, 12.

⁷Mining Journal. Minproc Meeting the Challenge of Global Markets. V. 316, Jan. 8, 1991, p. 51.

⁸Industrial Minerals. Streamlined TiO₂ Invests in World TiO₂ Expansions. No. 286, July 1991, p. 17.

⁹Metal Bulletin. New Indian Ti Sponge Plant. No. 7560, Feb. 25, 1991, p. 10.

¹⁰American Metal Market. Osaka Titanium Reports Sales Up. V. 99, No. 116, June 18, 1991, p. 5.

¹¹Metal Bulletin. Osaka Titanium Clips Sponge Output. No. 7577, May 2, 1991, p. 13.

¹²European Chemical News. Cyanamid Sells Out of TiO₂. V. 56, No. 1470, May 6, 1991, p. 4.

¹³Mining Journal. Sierra Leone License for Pioneer. Mar. 1, 1991, p. 158.

¹⁴Industrial Minerals. Natal Mineral Sands JV. No. 286, July 1991, p. 9-10.

¹⁵Work cited in footnote 8.

¹⁶Modern Paint and Coatings Journal. TiO₂ Demand To Rebound; Sulfate Plants at Risk. V. 81, No. 10, Oct. 1991, p. 12.

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TABLE 1
NATIONAL STOCKPILE PURCHASE SPECIFICATION:
TITANIUM SPONGE OR GRANULES, SUMMARY
OF CHEMICAL AND PHYSICAL REQUIREMENTS

	Type A ¹	Type B ¹	Type C ¹	Type D ¹
CHEMICAL REQUIREMENTS, ² PERCENTAGE				
Nitrogen	0.01	0.015	0.015	0.008
Carbon	.020	.025	.020	.020
Sodium	—	—	.190	.010
Magnesium	.08	.500	—	.080
Lithium	—	—	—	.090
Aluminum	—	.070	—	—
Chlorine	.1	.200	.200	.100
Iron	.08	.100	.040	.040
Silicon	.04	.040	.040	.040
Hydrogen	.005	.030	.050	.020
Oxygen	.1	.100	.100	.070
Water	.02	.020	.020	.020
Other elements, total	.05	.050	.050	.050
Titanium	99.6	99.1	99.3	99.6
PHYSICAL REQUIREMENTS				
Brinell hardness number, maximum	100	120	120	100
Particle size distribution, percentage:				
Minus 3/4 inch	100	100	100	100
Minus 1/2 inch	95	95	95	95
Plus 100 mesh	95	95	95	95

¹Type A—Magnesium reduced and finished by vacuum distillation; Type B—Magnesium reduced and finished by acid leaching or inert gas sweep distillation; Type C—Sodium reduced and finished by acid leaching; Type D—Electrolytic.

²All amounts are maximums except for titanium, which is a minimum.

Source: U.S. Department of Commerce, P-97-R7, June 2, 1982.

TABLE 2
NATIONAL STOCKPILE
PURCHASE SPECIFICATION:
SUMMARY OF RUTILE
CHEMICAL AND PHYSICAL¹
REQUIREMENTS

	Percentage by weight (dry basis)
Chemical requirements:²	
Titanium dioxide	95.00
Ferric oxide	1.0
Silica	1.3
Phosphorous pentoxide	.1
Sulfur	—
Zirconium dioxide	1.0
Alumina	.8
Vanadium pentoxide	.8
Chromium oxide	.8
Magnesium oxide plus calcium oxide	.3
Tin	.1
Manganese	—
Columbium pentoxide	.6

¹All rutile shall pass a U.S. Standard Sieve No. 30 (ASTM Designation E-11) with not more than 1% passing a U.S. Standard Sieve No. 200.

²All of the amounts are maximums except for titanium dioxide, which is a minimum. For radioactive identification, report for each lot the percent by weight of naturally occurring thorium, uranium, or combination of the two.

Source: U.S. Department of Commerce P-49-R6, Nov. 3, 1981.

TABLE 3
COMPOSITION OF TYPICAL COMMERCIAL TITANIUM CONCENTRATES

(Weight percentage)

	Ilmenite				Slag		Rutile	Synthetic rutile		
	United States		Norway, Tellnes	Australia, Bunbury	Canada, Sorel	Republic of South Africa, Richards Bay	Australia, East coast	United States, Kerr-McGee	Australia, Western Titanium	Japan, Isihara
	New York	Florida								
TiO ₂ (total)	46.1	64.0	45.0	54.4	80.0	¹ 85.0	95.2	94.15	92.0	96.1
Ti ₂ O ₃	—	—	—	—	16.0	² 25.0	—	—	10.0	—
Fe (total)	—	—	—	—	—	—	—	—	3.6	—
Fe (metallic)	—	—	—	—	—	—	—	—	.2	—
FeO	39.3	1.33	34.0	19.8	9.0	—	.9	—	—	—
Fe ₂ O ₃	6.7	28.48	12.5	19.0	—	—	1.0	2.6	—	1.3
SiO ₂	1.5	.28	2.8	.7	2.4	—	.2	1.3	.7	.5
Al ₂ O ₃	1.4	1.23	.6	1.5	2.9	—	.02	.48	.7	.46
CaO	.5	.007	.25	.04	.6	² .15	.07	.003	.03	.01
MgO	1.9	.20	5.0	.45	5.0	² 1.3	.18	.2	.15	.07
Cr ₂ O ₃	.009	—	.076	.02	.17	² .3	.6	.16	—	.15
V ₂ O ₅	.05	—	.16	.12	.57	² .6	.01	.16	.12	.20
MnO	.5	—	.25	1.4	.25	² 2.5	.008	.04	2.0	.03
S	.6	—	.05	.01	.06	—	.1	—	.15	—
Na ₂ O	—	—	—	—	—	—	.04	—	—	—
C	.22	—	.055	—	.05	—	.03	—	.15	—
P ₂ O ₅	.008	.12	.04	.02	—	—	.8	—	—	.17
ZrO ₂	.01	—	—	—	—	—	.2	—	—	.15
Nb ₂ O ₅	.01	.10	.01	.14	—	—	.03	—	—	.25
Ignition loss	1.3	—	—	.4	—	—	.1	.6	—	—

¹Minimum.

²Maximum.

Source: Technical publications and industry contacts.

TABLE 4
TIME-PRICE RELATIONSHIPS FOR TITANIUM

(Yearend price, dollars per pound)

Year	Rutile pigment (Ti content)		Sponge metal	
	Actual prices	Based on constant 1982 dollars	Actual prices	Based on constant 1982 dollars
1971	0.45	1.01	1.32	2.97
1972	.45	.97	1.32	2.84
1973	.50	1.01	1.42	2.87
1974	.72	1.33	2.25	4.17
1975	.73	1.23	2.70	4.55
1976	.78	1.24	2.70	4.28
1977	.81	1.20	2.98	4.43
1978	.85	1.18	3.28	4.54
1979	.98	1.25	3.98	5.06
1980	1.05	1.23	7.02	8.19
1981	1.25	1.33	7.65	8.14
1982	1.25	1.25	4.60	4.60
1983	1.25	1.20	4.10	3.95
1984	1.25	1.16	4.10	3.81
1985	1.30	1.17	3.75	3.38
1986	1.37	1.20	4.10	3.60
1987	1.37	1.17	4.10	3.49
1988	1.60	1.32	4.50	3.71
1989	1.75	1.39	5.05	4.00
1990	1.67	1.27	4.75	3.61
1991	1.64	NA	4.75	NA

NA Not available.

TABLE 5
U.S. IMPORT DUTIES

Tariff item	HTS No.	Most favored nation (MFN)	
		Jan. 1, 1991	Non-MFN Jan. 1, 1991
Ilmenite	2614.00.6020	Free	Free.
Titanium slag	2620.90.5000	do.	Do.
Rutile concentrate	2614.00.6040	do.	Do.
Synthetic rutile	2614.00.3000	5.0% ad valorem	30.0% ad valorem.
Waste and scrap metal	8108.10.1000	Free	Free.
Unwrought metal, including sponge	8108.10.50	15.0% ad valorem	25.0% ad valorem.
Wrought metal:			
Articles of titanium	8108.90.30	5.5% ad valorem	45.0% ad valorem.
Other	8108.90.60	15.0% ad valorem	45.0% ad valorem.
Titanium dioxide pigments	3206.10.00	6.0% ad valorem	30.0% ad valorem.
Titanium oxides	2823.00.0000	6.0% ad valorem	30.0% ad valorem.

TABLE 6
SALIENT TITANIUM STATISTICS

(Metric tons unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Ilmenite concentrate:					
Imports for consumption	307,515	394,170	411,751	345,907	213,886
Consumption	744,266	679,008	659,584	688,948	738,089
Titanium slag:					
Imports for consumption	408,785	434,641	386,146	373,623	408,302
Consumption	251,423	300,013	414,830	390,537	341,379
Rutile concentrate, natural and synthetic:					
Imports for consumption	197,937	231,124	264,895	274,605	240,120
Consumption	320,505	352,356	366,143	369,454	368,643
Sponge metal:					
Production	17,849	22,270	25,225	24,679	13,366
Imports for consumption	924	1,364	903	1,093	613
Consumption	17,973	21,003	24,927	23,207	13,976
Price, Dec. 31, per pound	\$4.00-\$4.20	\$4.25-\$4.75	\$4.80-\$5.30	\$4.50-\$5.00	\$4.50-\$5.00
Titanium dioxide pigment:					
Production	878,558	926,746	1,006,581	978,659	991,976
Imports for consumption	174,219	185,468	166,346	147,592	166,094
Consumption, apparent ¹	966,169	991,536	947,259	925,447	958,004
Price, Dec. 31, cents per pound:					
Anatase	77.0	95.0	102.0	99.0	99.0
Rutile	82.0	97.0	105.0	100.0	99.0
World: Production: (rounded)					
Ilmenite concentrate ²	*3,936,500	*4,033,200	*4,272,400	3,951,600	*3,485,700
Rutile concentrate, natural ²	439,180	433,900	454,140	475,100	*450,000
Titaniferous slag	1,575,000	1,725,000	1,765,000	1,432,000	*1,500,000

^{*}Estimated. [†]Revised.

¹Production plus imports minus exports plus stock decrease or minus stock increase.

²Excludes U.S. production data to avoid disclosing company proprietary data.

TABLE 7
U.S. TITANIUM METAL PRODUCTION CAPACITY IN 1991

Company	Ownership	Plant location	Yearend capacity (metric tons)	
			Sponge	Ingot ¹
Howmet Corp., Titanium Ingot Div.	Pechiney, France	Whitehall, MI	—	6,300
International Light Metals Corp.	Martin Marietta Corp.	Torrance, CA	—	5,000
A. Johnson Metals Corp.	Axel Johnson Group, Stockholm, Sweden	Lionville, PA	—	² 1,800
Lawrence Aviation Industries Inc.	Self	Port Jefferson, NY	—	1,400
Oregon Metallurgical Corp. (Oremet)	Oremet employees, 67%; public, 33%	Albany, OR	6,800	10,000
RMI Co.	USX Corp., 50%; public, 50%	Ashtabula, OH	10,900	—
		Niles, OH	—	16,300
Teledyne Allvac	Teledyne Inc.	Monroe, NC	—	³ 5,700
Teledyne Wah Chang Albany	do.	Albany, OR	—	900
Titanium Metals Corp. of America	Baroid Corp.	Henderson, NV	12,700	15,900
Viking Metallurgical Corp.	Quanex Corp.	Verdi, NV	—	³ 3,200
Wyman-Gordon Co.	Self	Worcester, MA	—	2,300
Total			30,400	68,800

¹Based on 7-day-per-week full production. Includes 61,700 tons vacuum arc double/triple melt, of which triple melt generally ranged from 10% to 30%. The remaining 7,100 tons was single-melt (electron-beam and plasma-arc) capacity for remelt electrodes and commercially pure ingot and slab.

²Single melt only.

³Includes 2,100 tons of single melt capacity.

**TABLE 8
COMPONENTS OF U.S. TITANIUM METAL SUPPLY AND DEMAND**

(Metric tons)

Component	1987	1988	1989	1990	1991
Production:					
Sponge	17,849	22,270	25,225	24,679	13,366
Ingot	33,762	38,856	41,306	36,809	24,884
Mill products	NA	27,837	29,946	25,619	22,263
Exports:¹					
Sponge	85	80	136	331	418
Other unwrought	204	210	1,173	3,102	2,144
Scrap	5,083	5,989	5,474	5,487	4,567
Ingot, slab, sheet bar, etc.	2,467	2,083	2,702	2,371	1,700
Other wrought	1,801	2,679	NA	NA	NA
Other articles of titanium	NA	NA	3,857	4,526	3,301
Total	9,640	11,041	13,342	15,816	12,130
Imports:¹					
Sponge	924	1,364	903	1,093	613
Scrap	2,218	4,235	5,308	3,037	2,668
Ingot and billet	68	237	190	162	25
Other unwrought	NA	NA	119	213	175
Other wrought (mill products)	892	822	1,049	988	757
Other articles of titanium	NA	NA	200	279	156
Total ²	4,101	6,658	7,770	5,772	4,394
Stocks, yearend:					
Government: Sponge (total inventory)	33,413	33,413	33,413	33,413	33,413
Industry:					
Sponge	2,272	2,439	2,114	3,267	2,852
Scrap	9,212	8,596	8,028	8,535	7,905
Ingot	4,044	3,933	3,548	3,725	2,826
Other	14	8	7	3	8
Total industry ²	15,542	14,977	13,697	15,530	13,591
Reported consumption:					
Sponge	17,973	21,003	24,927	23,207	13,976
Scrap	16,363	18,058	17,596	14,973	11,381
Receipts:					
Home	NA	NA	11,273	11,139	8,486
Purchased	NA	NA	12,583	9,710	7,313
Ingot	32,260	35,556	31,396	35,320	24,238
Mill products (net shipments):					
Forging and extrusion billet	10,968	10,694	11,742	10,729	7,454
Rod and bar	2,932	3,528	3,566	3,499	2,141
Other ³	6,318	8,336	9,689	9,695	6,005
Castings (shipments)	431	473	485	482	608

NA Not available.

¹Because of the implementation of the Harmonized Tariff System in Jan. 1989, import and export categories for 1989, 1990, and 1991 are not necessarily comparable with those in previous years.

²Data may not add to totals shown because of independent rounding.

³Data for sheet and strip, plate, extrusions (other than tubing), pipe and tubing, and other have been combined to avoid disclosing company proprietary data.

TABLE 9
CAPACITIES OF U.S. TITANIUM DIOXIDE PIGMENT PLANTS ON
DECEMBER 31, 1991¹

Company and plant location	Pigment capacity (metric tons per year)	
	Sulfate process	Chloride process
E.I. du Pont de Nemours & Co. Inc.:		
Antioch, CA	—	36,000
De Lisle, MS	—	245,000
Edge Moor, DE	—	129,000
New Johnsonville, TN	—	297,000
Kemira Inc., Savannah, GA	54,000	91,000
Kerr-McGee Chemical Corp., Hamilton, MS	—	96,000
Kronos Inc., Lake Charles, LA	—	80,000
SCM Chemicals Inc., Hanson Industries U.S.A.:		
Ashtabula, OH	—	111,000
Baltimore, MD	66,000	50,000
Total	120,000	1,135,000

¹The table does not include Hitox Corp.'s Corpus Christi, TX, production capacity of about 18,000 tons per year of buff TiO₂, which is made by refining and fine grinding of synthetic rutile.

TABLE 10
COMPONENTS OF U.S. TITANIUM DIOXIDE PIGMENT SUPPLY AND DEMAND

(Metric tons unless otherwise specified)

Component	1988		1989		1990		1991	
	Gross weight	TiO ₂ content						
Production	926,746	858,166	1,006,581	935,919	978,659	913,275	991,976	926,506
Shipments: ¹								
Quantity	1,097,481	1,020,517	1,126,622	1,046,633	1,116,431	1,045,748	1,124,194	1,052,350
Value thousands	\$1,954,656	\$1,954,656	\$2,352,390	\$2,352,390	\$2,404,282	\$2,404,282	\$2,381,906	\$2,381,906
Exports	118,422	*107,409	212,197	*193,311	202,288	*189,544	189,679	*177,539
Imports for consumption	185,468	*171,743	166,346	*154,669	147,592	*138,294	166,094	*155,464
Stocks, yearend	49,734	*46,053	63,205	*58,768	61,721	*57,597	72,108	*67,493
Consumption, apparent ²	991,536	*920,805	947,259	*884,562	925,447	*863,196	958,004	*896,692

¹Estimated.

²Includes interplant transfers.

³Production plus imports minus exports plus stock decrease or minus stock increase.

Sources: Bureau of the Census and U.S. Bureau of Mines.

TABLE 11
U.S. CONSUMPTION OF TITANIUM CONCENTRATES

(Metric tons)

Year	Ilmenite ¹		Titanium slag		Rutile (natural and synthetic) ²	
	Gross weight	TiO ₂ content ³	Gross weight	TiO ₂ content ³	Gross weight	TiO ₂ content ³
1987	744,266	463,072	251,423	202,688	320,505	301,534
1988	679,008	429,736	300,013	242,594	352,356	331,376
1989	659,584	419,743	414,830	335,395	366,143	345,989
1990:						
Alloys and carbide	(⁴)	(⁴)	(⁴)	(⁴)	—	—
Pigments	687,901	445,502	390,537	313,648	288,734	271,637
Welding-rod coatings and fluxes	(⁴)	(⁴)	—	—	4,295	4,047
Miscellaneous ⁵	1,047	726	(⁴)	(⁴)	76,425	71,373
Total	688,948	446,228	390,537	313,648	369,454	347,057
1991:						
Alloys and carbide	(⁴)	(⁴)	(⁴)	(⁴)	—	—
Pigments	737,414	476,145	341,379	273,976	315,742	286,741
Welding-rod coatings and fluxes	(⁴)	(⁴)	—	—	7,346	6,931
Miscellaneous ⁵	675	495	(⁴)	(⁴)	45,555	42,200
Total	738,089	476,640	341,379	273,976	368,643	335,872

¹Estimated.

²Includes a mixed product containing rutile, leucocoxene, and altered ilmenite.

³Includes synthetic rutile made in the United States.

⁴Included with "Miscellaneous" to avoid disclosing company proprietary data.

⁵Included with "Pigments" to avoid disclosing company proprietary data.

⁶Includes ceramics, chemicals, glass fibers, and titanium metal.

TABLE 12
U.S. DISTRIBUTION OF DOMESTIC TITANIUM PIGMENT SHIPMENTS,
TITANIUM DIOXIDE CONTENT, BY INDUSTRY

(Percentage)

Industry	1987	1988	1989	1990	1991
Ceramics	W	0.4	0.4	W	W
Coated fabrics and textiles	0.3	W	.4	0.2	W
Floor coverings	1.2	1.2	1.1	1.0	W
Paint, varnish, lacquer	49.5	48.1	50.0	48.9	46.6
Paper	24.3	24.2	25.8	26.5	26.4
Plastics	17.0	17.0	16.3	16.6	16.8
Printing ink	1.2	1.7	.8	1.6	1.8
Roofing granules	.4	.4	.3	.4	W
Rubber	1.8	1.7	1.4	1.5	1.8
Other	4.3	5.3	3.5	3.3	6.6
Total	100.0	100.0	100.0	100.0	100.0

W Withheld to avoid disclosing company proprietary data; included in "Other."

TABLE 13
U.S. CONSUMPTION OF TITANIUM PRODUCTS¹ IN STEEL AND OTHER ALLOYS

(Metric tons)

	1987	1988	1989	1990	1991
Carbon steel	711	877	W	*1,530	1,479
Stainless and heat-resisting steel	2,229	2,742	2,647	*2,469	1,927
Other alloy steel (includes HSLA)	325	249	149	*157	170
Tool steel	W	W	W	W	W
Total steel²	3,265	3,868	2,796	*4,156	3,576
Cast irons	W	W	W	W	34
Superalloys	625	642	800	*836	688
Alloys, other than above	290	1,552	873	*973	665
Miscellaneous and unspecified	41	54	1,600	*67	15
Total consumption²	4,221	6,116	6,069	*6,032	4,977

¹Revised. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

²Includes ferrotitanium containing 20% to 70% titanium and titanium metal scrap.

³Data may not add to totals shown because of independent rounding.

TABLE 14
U.S. STOCKS OF TITANIUM CONCENTRATES AND PIGMENT, DECEMBER 31

(Metric tons)

	Gross weight	TiO ₂ content
Ilmenite:¹		
1989	236,679	137,643
1990	341,891	196,645
1991	250,762	146,129
Titanium slag:¹		
1989	96,067	78,078
1990	85,960	68,605
1991	88,079	72,280
Rutile:¹		
1989	155,024	144,618
1990	171,085	161,026
1991	208,030	196,526
Titanium pigment:²		
1989	63,205	*58,768
1990	61,721	*57,597
1991	72,108	*68,503

¹Estimated.

²Producer, consumer, and dealer stocks.

³Bureau of the Census. Producer stocks only.

TABLE 15
PUBLISHED PRICES OF TITANIUM CONCENTRATES AND PRODUCTS¹

		1990		1991	
Concentrates:					
Ilmenite, f.o.b. eastern U.S. ports	per metric ton		(²)		(²)
Ilmenite, f.o.b. Australian ports	do.	\$69.00	-\$77.00	\$68.00	-\$76.00
Ilmenite, large lots, bulk, f.o.b. U.S. east coast	do.		NA		NA
Rutile, bagged, f.o.b. Australian ports	do.	693.00	-770.00	515.00	-545.00
Rutile, bulk, f.o.b. Australian ports	do.	732.00	-847.00	537.00	-552.00
Rutile, large lots, bulk, f.o.b. U.S. east coast	do.	550.00	-580.00	606.00	-650.00
Synthetic rutile, f.o.b. Mobile, AL	do.		NA		NA
Titanium slag, 80% TiO ₂ , f.o.b. Sorel, Quebec*	do.	270.00	-290.00	280.00	-305.00
Titanium slag, 85% TiO ₂ , f.o.b. Richards Bay, Republic of South Africa*	do.	285.00	-310.00	295.00	-325.00
Metal:					
Sponge, reported sales	per pound	4.50	-5.00	4.50	-5.00
Sponge, Japanese, under contract, c.i.f. U.S. ports, including import duty	do.		No quotation		No quotation
Mill products:					
Bar	do.	11.50	-13.24	11.50	-13.24
Billet	do.	7.80	-9.59	7.80	-9.59
Plate	do.	12.80	-13.75	12.80	-13.75
Sheet	do.	9.60	-11.60	9.60	-11.60
Strip	do.	10.70	-12.57	10.70	-12.57
Scrap:					
Cuttings, commercially pure	do.		NA		NA
Turnings, commercially pure	do.		NA		NA
Turnings, unprocessed	do.	1.05	-1.15	.80	-.90
Pigment:					
Titanium dioxide pigment, f.o.b. U.S. plants anatase	do.		.99		.99
Titanium dioxide pigment, f.o.b. U.S. plants, rutile	do.		1.01		.99

*Estimated. NA Not available.

¹Yearend.

²List price suspended effective Jan. 1, 1985.

Sources: American Metal Market, American Paint and Coatings Journal, Chemical Marketing Reporter, Industrial Minerals (London), Metal Bulletin, Metals Week, and industry contacts.

TABLE 16
U.S. EXPORTS OF TITANIUM PRODUCTS, BY CLASS

Class	1989		1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Metal:						
Sponge	136	\$910	331	\$2,073	418	\$2,604
Scrap	5,474	22,909	5,487	22,443	4,568	10,706
Ingots, billets, slabs, etc.	NA	NA	NA	NA	NA	NA
Other unwrought	NA	NA	NA	NA	NA	NA
Billet	1,128	21,765	969	17,890	513	8,087
Blooms and sheet bars	1,240	27,630	887	23,417	1,038	21,390
Ingot	334	5,471	514	7,426	149	2,437
Other	1,173	8,906	3,102	20,502	2,145	15,919
Wrought	NA	NA	NA	NA	NA	NA
Bars and rods	1,848	49,969	1,697	54,244	1,147	34,833
Other	2,009	60,542	2,829	94,046	2,153	78,227
Total ¹	13,342	198,102	15,816	242,040	12,131	174,203
Ores and concentrates	19,832	5,900	18,765	7,398	26,912	10,167
Pigment and oxides:						
Titanium dioxide pigments	68,485	141,359	153,361	327,009	146,187	272,833
Titanium oxides	143,712	296,286	48,927	107,551	43,492	76,683
Titanium compounds, except pigment-grade	NA	NA	NA	NA	NA	NA
Total	212,197	437,645	202,288	434,560	189,679	349,516

NA Not available.

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 17
U.S. IMPORTS FOR CONSUMPTION OF TITANIUM CONCENTRATES,
BY COUNTRY

Concentrate and country	1989		1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Ilmenite:						
Australia	317,835	\$20,335	326,186	\$22,206	213,886	\$24,071
India	—	—	19	36	—	—
Sierra Leone	52,261	2,895	19,701	720	—	—
Sri Lanka	30,400	1,672	—	—	—	—
St. Pierre and Miquelon ¹	11,255	598	—	—	—	—
Total²	411,751	25,500	345,907	22,962	213,886	24,071
Titanium slag:						
Canada	117,609	25,260	99,510	22,434	73,346	19,084
Norway	—	—	5,581	1,271	5,257	1,200
South Africa, Republic of	268,537	59,851	268,531	65,745	329,691	85,500
Other	—	—	—	—	8	8
Total	386,146	85,111	373,623	89,450	408,302	105,792
Rutile, natural:						
Australia	108,380	54,213	120,686	68,885	57,388	33,170
Canada	82	28	379	22	113	60
Mexico	1,050	35	—	—	—	—
Netherlands	—	—	1,943	1,493	—	—
Sierra Leone	32,793	17,294	52,776	24,467	76,368	33,545
South Africa, Republic of	46,252	19,591	42,234	16,626	40,460	19,773
Other	68	554	9	133	538	130
Total²	188,625	91,715	218,026	111,627	174,866	86,678
Rutile, synthetic:						
Australia	64,190	22,517	52,578	13,632	59,091	31,564
Brazil	—	—	2	5	—	—
India	9,101	4,179	4,000	2,400	—	—
Japan	2,979	1,515	—	—	—	—
Malaysia	—	—	—	—	6,163	3,390
Netherlands	(³)	2	—	—	—	—
Total²	76,270	28,213	56,579	16,037	65,254	34,953
Titaniferous iron ore:⁴						
Canada	37,922	1,876	28,818	2,169	27,012	1,593

¹Country of transshipment rather than country of origin.

²Data may not add to totals shown because of independent rounding.

³Less than 1/2 unit.

⁴Includes materials consumed for purposes other than production of titanium commodities, principally heavy aggregate and steel-furnace flux.

Source: Bureau of the Census. Data adjusted by the U.S. Bureau of Mines.

TABLE 18
U.S. IMPORTS FOR CONSUMPTION OF TITANIUM PIGMENTS, BY
COUNTRY

(Metric tons)

Country	1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
80% or more titanium dioxide:				
Australia	—	—	172	\$269
Belgium	5,046	\$8,542	6,776	11,200
Canada	37,235	60,481	37,554	63,115
China	1,027	1,128	1,757	1,793
Finland	2,301	4,450	2,286	4,166
France	1,755	3,611	2,428	4,524
Germany, Federal Republic of	17,165	32,033	20,706	39,966
Japan	3,847	7,822	4,610	8,642
Mexico	3,632	6,768	13	3
Netherlands	—	—	206	336
Norway	4,399	7,466	4,939	8,352
Singapore	3,536	6,340	4,213	6,419
United Kingdom	185	364	239	596
Other	115	127	1,203	1,786
Total	80,243	139,132	87,102	151,167
Other titanium dioxide:				
Belgium	399	706	170	276
Canada	4,409	7,776	4,834	10,129
France	12,880	22,934	15,997	25,419
Germany, Federal Republic of	2,898	7,493	1,724	6,078
Italy	1,789	3,161	2,505	4,187
Norway	675	1,065	—	—
South Africa, Republic of	148	254	226	366
Spain	9,181	15,838	6,064	8,900
United Kingdom	12,196	21,226	19,516	31,688
Other	362	1,076	1,480	2,598
Total	44,937	81,529	52,516	89,641
Titanium oxide:				
Australia	—	409	1,021	1,681
Belgium	113	249	946	1,531
Canada	5,266	24,777	5,305	7,980
China	139	908	483	546
Finland	150	1,546	271	464
France	4,469	9,056	4,687	7,308
Germany, Federal Republic of	2,198	993	5,526	10,182
Japan	94	1,781	58	573
Mexico	159	1,789	40	59
Norway	468	771	1,110	1,869

See footnotes at end of table.

TABLE 18—Continued
**U.S. IMPORTS FOR CONSUMPTION OF TITANIUM PIGMENTS, BY
 COUNTRY**

(Metric tons)

Country	1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Titanium oxide—Continued:				
United Kingdom	9,301	16,497	6,425	11,064
Yugoslavia	—	—	78	120
Other	55	165	527	1,105
Total	22,412	58,941	26,477	44,482
Grand total¹	147,592	279,602	166,094	285,290

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 19
U.S. IMPORTS FOR CONSUMPTION OF TITANIUM METAL, BY CLASS AND COUNTRY

Class and country	1989		1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Unwrought:						
Sponge:						
China	225	\$1,709	116	\$842	94	\$600
Japan	649	6,203	934	9,057	357	3,484
United Kingdom	9	109	26	367	55	894
Other	20	160	17	133	106	473
Total¹	903	8,181	1,093	10,398	612	5,451
Waste and scrap:						
Austria	142	1,209	72	402	—	—
Belgium	8	50	18	73	67	169
Canada	480	3,517	228	791	186	586
China	173	1,225	268	1,528	66	227
El Salvador	111	736	—	—	—	—
France	216	1,451	283	1,448	125	500
Germany, Federal Republic of	303	2,719	52	282	205	704
Japan	2,121	15,482	1,004	5,799	475	1,733
Sweden	87	587	77	665	100	267
U.S.S.R.	524	4,007	397	2,680	443	1,195
United Kingdom	919	9,204	521	3,230	815	2,694
Other	224	1,711	117	653	185	428
Total¹	5,308	41,898	3,037	17,550	2,666	8,503
Ingot and billets:						
Hong Kong	86	713	—	—	—	—
Japan	36	527	162	47	3	661
United Kingdom	68	862	—	—	20	424
Other	—	—	—	—	1	10
Total¹	190	2,102	162	47	24	1,095
Powder:						
Israel	31	887	18	431	22	522
Other	6	374	2	95	12	175
Total	37	1,261	20	526	34	697
Other:²						
Japan	—	—	24	519	3	121
Netherlands	—	—	1	2	18	203
Switzerland	—	—	—	—	36	407
United Kingdom	33	433	139	1,686	63	751
Other	49	4,540	29	152	21	79
Total¹	82	4,973	193	2,359	141	1,561
Wrought titanium:³						
Canada	638	14,693	755	17,802	391	9,337
France	17	516	17	548	41	515

See footnotes at end of table.

TABLE 19—Continued
U.S. IMPORTS FOR CONSUMPTION OF TITANIUM METAL, BY CLASS AND COUNTRY

Class and country	1989		1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Wrought titanium—Continued:						
Germany, Federal Republic of	25	\$792	20	\$379	60	\$1,115
Japan	474	11,671	352	9,858	317	8,350
Sweden	16	3,165	6	429	7	431
United Kingdom	56	1,584	95	5,173	68	2,799
Other	24	1,664	22	1,557	30	1,466
Total¹	1,250	34,085	1,266	35,746	914	24,014

¹Data may not add to totals shown because of independent rounding.

²Includes blooms, sheet, bars, slabs, and other unwrought.

³Includes bars, castings, foil, pipes, plates, profiles, rods, sheet, strip, tubes, wire, and other.

Source: Bureau of the Census.

TABLE 20
WORLD TITANIUM ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1991

[Thousand metric tons of TiO₂ content of concentrates, gross weight of sponge (over 99% Ti), and gross weight of pigment (average about 95% TiO₂)]

	Ilmenite	Rutile	Rutile, synthetic	Sponge metal	TiO ₂ pigment		Total
					Sulfate ¹	Chloride ²	
North America:							
Canada	880	—	—	—	74	38	112
Mexico	—	—	—	—	—	99	99
United States	217	30	100	30	120	1,135	1,255
Total	1,097	30	100	30	194	1,272	1,466
South America: Brazil	83	15	—	—	55	—	55
Europe:							
Belgium	—	—	—	—	70	—	70
Czechoslovakia	—	—	—	—	22	—	22
Finland	—	—	—	—	80	—	80
France	—	—	—	—	225	—	225
Germany, Federal Republic of	—	—	—	—	270	80	350
Italy	—	—	—	—	75	—	75
Netherlands	—	—	—	—	—	45	45
Norway	450	—	—	—	27	—	27
Poland	—	—	—	—	36	—	36
Spain	—	—	—	—	65	—	65
U.S.S.R.	250	10	—	52	100	—	100
United Kingdom	—	—	—	5	105	195	300
Yugoslavia	—	—	—	—	28	—	28
Total	700	10	—	57	1,103	320	1,423
Africa:							
Sierra Leone	35	120	—	—	—	—	—
South Africa, Republic of	850	94	—	—	35	—	35
Total	885	214	—	—	35	—	35
Asia:							
China	90	—	—	3	25	—	25
India	200	19	138	—	12	22	34
Japan	—	—	46	27	274	54	328
Korea, Republic of	—	—	—	—	18	—	18
Malaysia	275	—	96	—	—	—	—
Saudi Arabia	—	—	—	—	—	50	50
Singapore	—	—	—	—	—	36	36
Sri Lanka	80	13	—	—	—	—	—
Taiwan	—	—	—	—	10	—	10
Thailand	16	—	—	—	—	—	—
Total	661	32	280	30	339	162	501
Oceania: Australia	1,100	260	250	—	35	70	105
World total (may be rounded)	4,526	561	630	117	1,760	1,824	3,585

¹Sulfate process.

²Chloride process.

³Contained in 80% TiO₂ slag made from ilmenite.

⁴Mainly anatase.

⁵Contained in 85% TiO₂ slag made from ilmenite.

Sources: Technical publications, especially Industrial Minerals; industry contacts; and U.S. Bureau of Mines estimates.

TABLE 21
U.S. TITANIUM RESERVES AND RESERVE BASE IN 1991

(Thousand metric tons of TiO₂ content)

	Reserves			Reserve base ¹		
	Ilmenite	Rutile	Total	Ilmenite and perovskite ²	Rutile and anatase ³	Total
Arkansas	—	—	—	—	200	200
California	—	—	—	600	—	600
Colorado	—	—	—	9,800	—	9,800
Florida	7,800	300	8,100	7,800	300	8,100
New York	—	—	—	7,900	—	7,900
Tennessee	—	—	—	5,600	900	6,500
Virginia	—	—	—	1,600	—	1,600
Total	7,800	300	8,100	33,300	1,400	34,700

¹The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves) and some of those that are currently subeconomic (subeconomic resources).

²Ilmenite except for the 9.8 million tons in Colorado perovskite.

³Rutile except for the 200,000 tons in Arkansas anatase.

TABLE 22
WORLD TITANIUM RESERVES AND RESERVE BASE IN 1991

(Thousand metric tons of TiO₂ content¹)

	Reserves			Reserve base ³		
	Ilmenite	Rutile and anatase ²	Total	Ilmenite and perovskite ⁴	Rutile and anatase ²	Total
North America:						
Canada	27,000	—	27,000	73,000	—	73,000
United States	7,800	300	8,000	33,300	1,400	35,000
Total	35,000	300	35,000	106,300	1,400	108,000
South America:						
Brazil	1,600	66,000	68,000	1,600	86,000	88,000
Europe:						
Finland	1,400	—	1,400	1,400	—	1,400
Italy	—	—	—	9,000	21,000	30,000
Norway	32,000	—	32,000	90,000	—	90,000
U.S.S.R.	5,900	2,500	8,400	13,000	2,500	16,000
Total	39,000	2,500	42,000	113,000	24,000	137,000
Africa:						
Egypt	—	—	—	1,400	—	1,400
Madagascar	—	—	—	15,000	—	15,000
Mozambique	2,300	100	2,400	2,300	100	2,400
Sierra Leone	1,000	2,000	3,000	1,000	2,000	3,000
South Africa, Republic of	36,000	3,600	40,000	45,000	4,500	50,000
Total	39,000	5,700	45,000	65,000	6,600	72,000
Asia:						
China	30,000	—	30,000	41,000	—	41,000
India	31,000	4,400	35,400	31,000	4,400	35,000
Malaysia	—	—	—	1,000	—	1,000
Sri Lanka	3,600	800	4,400	3,800	800	4,600
Total	65,000	5,200	70,000	77,000	5,200	82,000
Oceania:						
Australia	24,000	5,300	29,000	66,000	42,000	108,000
World total	204,000	85,000	289,000	428,000	167,000	595,000

¹Data may not add to totals shown because of independent rounding.

²Mainly anatase in Brazil; rutile elsewhere.

³The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).

⁴Ilmenite except for 9.8 million tons in Colorado perovskite.

TABLE 23
TITANIUM: WORLD PRODUCTION OF CONCENTRATES (ILMENITE, LEUCOXENE, RUTILE, AND TITANIFEROUS SLAG), BY COUNTRY¹

(Metric tons)

Concentrate type and country	1987	1988	1989	1990	1991 ^a
Ilmenite and leucoxene:²					
Australia:					
Ilmenite	1,498,087	1,610,175	1,696,000	¹ 1,602,000	³ 1,363,000
Leucoxene	11,290	11,742	18,000	19,000	³ 18,000
Brazil	¹ 169,303	¹ 142,167	¹ 144,200	¹ 114,117	120,000
China ^a	140,000	150,000	150,000	150,000	150,000
India ^a	140,000	140,000	160,000	160,000	160,000
Malaysia	509,202	486,305	⁵ 533,637	⁵ 530,237	³ 336,347
Norway	852,322	898,035	929,830	⁸ 814,488	800,000
Portugal	141	59	111	⁴ 3	40
Sierra Leone	5,600	42,118	62,310	54,639	⁶ 60,400
Sri Lanka	128,500	74,305	¹ 101,354	⁶ 66,413	⁶ 60,861
Thailand	27,078	18,254	16,985	10,674	³ 17,071
U.S.S.R. ^a	455,000	460,000	460,000	430,000	400,000
United States	W	W	W	W	W
Total	3,936,523	4,033,160	4,272,427	3,951,611	3,485,719
Rutile:					
Australia	246,263	230,637	243,000	² 245,000	² 201,000
Brazil	324	1,514	2,600	¹ 1,814	2,000
India ^a	7,000	5,000	5,000	5,000	5,000
Sierra Leone	113,300	126,358	128,340	144,284	³ 154,800
South Africa, Republic of ^b	55,000	55,000	60,000	⁷ 64,056	75,000
Sri Lanka	7,200	5,255	⁵ 5,589	⁵ 5,460	³ 3,080
Thailand	92	128	—	—	⁷ 76
U.S.S.R. ^a	10,000	10,000	10,000	9,500	9,000
United States	W	W	W	W	W
Total	439,179	433,892	454,529	475,114	449,956
Titaniferous slag:					
Canada ^{a 4}	925,000	1,025,000	1,040,000	760,000	600,000
South Africa, Republic of ⁵	650,000	700,000	725,000	⁸ 840,000	900,000
Total	1,575,000	1,725,000	1,765,000	¹1,600,000	1,500,000

^aEstimated. ^bRevised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

¹Table excludes production of unbeneficiated anatase ore in Brazil, in metric tons, as follows: 1987—3,344,318; 1988—3,400,000; 1989—3,500,000 (estimated); 1990—3,000,000 (estimated, revised); and 1991—3,000,000 (estimated). This material reportedly contains 20% TiO₂. Table contains data available through June 17, 1992.

²Ilmenite is also produced in Canada and in the Republic of South Africa, but this output is not included here because an estimated 90% of it is duplicative of output reported under "Titaniferous slag," and the rest is used for purposes other than production of titanium commodities, principally as steel furnace flux and heavy aggregate.

³Reported figure.

⁴Contains 80% TiO₂.

⁵Contains 85% TiO₂.

TUNGSTEN

By Gerald R. Smith

Mr. Smith, a physical scientist with 28 years of research and commodity experience with the U.S. Bureau of Mines, has been the commodity specialist for tungsten since 1986. Domestic survey data were prepared by Cheryl Mack, statistical assistant; the world production table was prepared by Ronald Hatch, international data coordinator.

The unique high-temperature properties of tungsten and its alloys can be utilized advantageously in the production of numerous end-use items. The high melting point, high density, good corrosion resistance, and good thermal and electrical conductivity properties of tungsten and its alloys and the excellent cutting and wear-resistant properties of its carbide continue to provide important items for consumption in both the domestic and military sectors.

Total domestic consumption of tungsten in primary end-use categories decreased by about 6% in 1991 compared with that of 1990. Weakness during the last half of the year in the demand for cemented carbides in the combined cutting tool, mining tool, oil drilling equipment, and wear-resistant component industries contributed significantly to this decline. Demand for other tungsten-containing products such as steels, superalloys, and mill products also decreased during the year.

The average price for wolframite concentrate on the world market increased by 22% in 1991, while scheelite prices remained essentially unchanged compared with those of 1990. Most U.S. tungsten mines still remained closed, as the owners and operators viewed their operations as continuing to be noncompetitive at existing prices.

An Orderly Marketing Agreement (OMA) limiting imports of ammonium paratungstate (APT) and tungstic acid from China since October 1, 1987, was allowed to expire on September 30, 1991. No further trade restrictions were placed on these materials for the remainder of the year. On October 28, 1991,

however, a final decision was made by the International Trade Commission (ITC) to place a tariff of 151% on imports of tungsten ore concentrates from China.

A summary of the important U.S. and international statistics for 1991 and the previous 4 years are shown in table 1.

DOMESTIC DATA COVERAGE

Domestic production data for tungsten are developed by the U.S. Bureau of Mines by means of three separate, voluntary surveys. These surveys are "Tungsten Ore and Concentrate," "Tungsten Concentrate and Tungsten Products," and "Tungsten Concentrate." Of the 47 known mining and processing operations to which survey requests were sent, 96% responded, and are represented in the production and stock totals shown in table 1.

BACKGROUND

Definitions

Tungsten, a silvery gray metal, has an atomic number of 74 and an atomic weight of 183.92. Its most outstanding physical property is its high melting point of 3,410° C, the highest of all metals. Tungsten is one of the heaviest of elements, with a density of 19.3 grams per cubic centimeter at 20° C. It has good corrosion resistance, good thermal and electrical conductivity, and a low coefficient of expansion. At temperatures above 1,650° C, tungsten has the highest tensile strength of all metals.

Tungsten concentrate is sold in units of tungsten trioxide (WO₃). In the United

States, sales are based on the short ton unit of WO₃. This is equivalent to 1% of a short ton, or 20 pounds of WO₃ and contains 7.19 kilograms (15.86 pounds) of tungsten. In most other countries, tungsten is sold in the metric ton unit (mtu) and contains 7.93 kilograms (17.48 pounds) of tungsten.

Natural or synthetic scheelite concentrate, in nodular form, is ideal for direct addition to steel melts because the calcium is removed as slag. Fine material in either synthetic or natural scheelite is not desirable because of high dust losses. Wolframite concentrate is not satisfactory for steelmaking because of the manganese and tin content.

Tungsten ores and concentrates are converted into the following intermediate products: APT, tungstic acid, sodium tungstate, tungsten metal powder, and tungsten carbide powder. Most of the APT is reduced to tungsten metal powder, which then is processed into tungsten carbide powder.

Tungsten alloys and tungsten mill products such as rod, wire, and sheet are produced from hydrogen-reduced tungsten metal powder. The tungsten carbide produced from powder is cemented, usually with cobalt, to form various cutting and wear-resistant tools and parts.

Tungsten chemicals (APT, tungstic acid, and sodium tungstate) are produced as coproducts at some tungsten processing plants and as primary products at others. When not processed further into metal powder, they generally are used in the chemical industry.

Products for Trade and Industry

Tungsten materials can be divided into four major classes, depending on use: (1) a carbide in cutting and wear-resistant materials, and welding and hard-facing rods; (2) mill products made from essentially pure metal; (3) an alloy constituent in high-speed and tool and die steels, superalloys, and nonferrous alloys; and (4) various chemicals and compounds for nonmetallurgical applications.

The extreme hardness of tungsten carbide at temperatures exceeding 1,000° C makes it a preferred metalworking material for cutting edges of machine tools subject to intense wear or abrasion and for metal surfaces in forming and shaping dies. The mining and petroleum industries use tungsten carbide in drill bits, in the cutting edges of earth-moving equipment, and in crushing machinery. Tungsten carbide is used widely in wear parts of transportation and electrical equipment.

In most applications, tungsten carbide generally is cemented with a powdered cobalt metal binder by compaction and sintering. The cobalt content can range from about 3 to 25 weight-percent, with the higher content providing greater shock resistance at a sacrifice in hardness. Tantalum and/or titanium carbides are used in conjunction with tungsten carbide in certain cutting and chipping tools. Also, coatings such as titanium carbide, titanium nitride, and aluminum oxide on tungsten carbide are used extensively to increase the life of inserts for machining applications.

Mill products made from pure or substantially pure tungsten metal powder are used in significant quantities by the electrical and electronic industries. Tungsten wire is used as the filament in electric lamps and as cathodes for electronic tubes. Disks produced from tungsten rods or sheet are used in automotive distributor points, although this end use is declining as the number of automobiles with electronic ignition systems increases. They are also used as contact points in numerous manufactured products. Tungsten metal is employed as heat and radiation shielding, as electrodes

for inert-gas welding, as components of X-ray and cathode ray tubes, and as heating elements in high-temperature resistance furnaces. Tungsten metal is used by the aerospace industry because it retains its strength at elevated temperature in reducing or inert atmospheres. The use of tungsten as a heavy metal for counterweights and balances, especially by the aircraft industry, has been replaced, to a significant extent, by depleted uranium, which approaches the density of tungsten.

Cast tungsten carbide is used principally as a hard-facing material. In this application, carbide particles are applied by a welding process to provide an abrasion-resisting surface layer on the surface to be coated. The carbide may be initially in the form of rod or loose grains in a tube.

As an alloy constituent, tungsten is used primarily in the production of high-speed steels and tool and die steels. Hardness and oxidation resistance at elevated temperatures are the most important properties possessed by these steels, which are used for machinery and equipment in the metalworking, construction, and mining industries. Certain grades of stainless and other alloy steels contain tungsten to improve wear and abrasion resistance, shock resistance, corrosion resistance, and/or strength at high temperatures.

Tungsten is an important constituent in a wide variety of superalloys and nonferrous alloys. Tungsten-containing superalloys are being utilized increasingly in high-temperature applications for their high-temperature strength and oxidation resistance. Tungsten alloyed with copper or silver is used for electrical contacts to provide wear resistance with adequate electrical conductivity.

Nonmetallurgical applications of tungsten include chemicals used in textile dyes, paints, enamels, toners, and coloring glass. Certain tungsten compounds are luminescent and used as phosphors in pigments, X-ray screens, television picture tubes, and fluorescent lighting. Sodium tungstate is employed as a corrosion inhibitor and a fireproofing agent in textiles. APT is used in making

catalysts for the refining of petroleum. Among other chemical applications, tungsten compounds are used in chemical-vapor deposition, as catalysts in other chemical processing, and as laboratory reagents.

The chief nonindustrial use of tungsten is in armor-piercing ordnance, but this has been replaced, in part, by depleted uranium.

ANNUAL REVIEW

Legislation and Government Programs

The National Defense Authorization Acts covering fiscal years 1991 and 1992 included no authority for disposal of tungsten from the National Defense Stockpile for calendar year 1991.

In July 1991, the Department of Defense issued a report recommending revisions in stockpile goals, including a new proposed goal for stockpile-grade tungsten materials that was about 3,992 metric tons (8.8 million pounds) of contained tungsten less than the existing inventory level of approximately 26,470 metric tons (58.5 million pounds), shown in table 2. However, the National Defense Authorization Act for Fiscal Years 1992 and 1993, effective October 1, 1991, included no changes in the goal for tungsten materials in the National Defense Stockpile.

Strategic Minerals Corp., Danbury, CT, through its subsidiary U.S. Tungsten Corp., operator of the Pine Creek Mine, Bishop, CA, filed a petition on January 23, 1991, with the ITC charging that China was dumping tungsten ore concentrates on the U.S. market. Following its investigation of this case, the Department of Commerce, International Trade Administration (ITA), issued its final determination on September 20, 1991. Consistent with its preliminary findings of July 10, 1991, the ITA determined that imports of tungsten ore concentrates from China were being, or were likely to be, sold in the United States at less than fair market value and were declared subject to additional tariff. Accordingly, the U.S. Customs Service was directed to continue to suspend

liquidation (defer final import processing) of all entries of tungsten ore concentrates from China in a manner similar to that which it had been directed earlier following ITA's preliminary findings. Final import processing was contingent upon receipt of a cash deposit or posting of a bond on all such entries, the amount of which was equivalent to the established margin of 151%, that is, the extent to which the determined foreign market value exceeded the U.S. sales price. The merchandise covered by the ITA's investigation included all concentrated or upgraded forms of raw tungsten ore. Upon completion of its investigation, the ITA reported its findings to the ITC. Subsequently, the tariff decision became final on October 28, 1991, when the ITC, in a 4 to 0 vote of the Commissioners, ruled that a U.S. industry was materially injured or was threatened with material injury, by reason of imports of tungsten ore concentrates from China at less than fair market value. Under existing antidumping procedures, the imposed tariff will remain in effect indefinitely.

The OMA, limiting U.S. imports of APT and tungstic acid from China since October 1, 1987, was allowed to expire on September 30, 1991. The U.S. Government decision was made following final discussions and a subsequent vote by an interagency trade policy review group. Prior to the decision, U.S. Government and industry officials discussed the necessity for alternative trade control measures upon expiration of the OMA. Among the measures given significant consideration by the industry was the possibility of negotiating a new agreement with China that included additional downstream tungsten materials through metal powder and tungsten carbide powder.

Strategic Considerations

Tungsten is an important strategic material necessary for defense purposes, including the industrial base. Currently, the heavy-metal alloys of tungsten, containing 3% to 10% nickel and small quantities of iron or copper, are used in several of the smaller diameter projectiles

for penetrating armorplate. Cemented tungsten carbide parts, which exhibit excellent cutting and wear-resistant properties, are vital to the U.S. metalworking, machining, construction, transportation, mining, and oil and gas drilling industries. Tungsten mill products and powders are essential to the lamp and lighting industry as filaments and electrodes, to the electrical and electronic industries as wear-resistant, electrically conductive contact surfaces, and to the superalloy and steel industries as alloying components. The U.S. Department of Defense relies heavily on the maintenance of a broad domestic production base to cover mobilization contingencies. The entire tungsten industry, from mined ore to manufactured products, thus represents an important component of the U.S. defense policy. The Department of Defense continually assesses the U.S. ability to produce tungsten to ensure that this and other sources of supply are sufficient to meet current and projected levels of demand necessary to preserve the national defense. A proposal by the Department of Defense in mid-1991 contained a recommendation that the quantity of tungsten in the National Defense Stockpile be decreased by about 15%. Tungsten, like many other metals and materials in the stockpile, was being considered for sale, in part, as a result of changing political climates in the world and military downsizing.

Issues

During 1991, China continued to be the principal supplier of tungsten products to the world market. Although wolframite concentrate prices increased during the year, the price level for concentrates and intermediate materials remained too low for many market economy producers to compete on the world market. China's perceived failure to place adequate controls on its production, distribution, and pricing policies continued to dominate the discussions among domestic industry officials. Most tungsten mines in the United States remained closed or were

operated at reduced capacity during the year. Furthermore, market conditions generally offered little or no economic incentive for producers to explore or develop other tungsten resources, prompting a request to the U.S. Government for trade restraints on China. U.S. Tungsten Corp., a subsidiary of Strategic Metals Corp., Danbury, CT, and the operator of the Pine Creek tungsten mine and mill, Bishop, CA, filed a petition on behalf of the U.S. tungsten mining industry requesting relief from alleged dumping of tungsten ore concentrate by China. Subsequent investigations by the Department of Commerce's ITA and the ITC resulted in an affirmative antidumping ruling and the levying of a significant tariff on imports of ore concentrates from China. Although the antidumping ruling provided significant protection from imports of concentrate, related action regarding imports of certain downstream products added other uncertainties to the U.S. tungsten market. The expiration of the OMA limiting imports of APT and tungstic acid effectively eliminated all constraints on imports of downstream tungsten products from China. In subsequent discussions between Government and industry officials, the possibility of instituting trade restrictions on all downstream products through tungsten carbide powder was considered, but by yearend, no official request for an investigation was filed by the U.S. industry. Imports of tungsten from China, however, did shift noticeably from ore concentrates to downstream intermediate materials, including APT, tungsten oxide, and sodium tungstate, following the imposition of the antidumping tariff on ore concentrates.

Several internal constraints on production and sale of tungsten products reportedly were instituted by the Government of China during 1991. The effect of these constraints on the supply-demand balance for tungsten products on the world market will require additional time and further assessment.

Production

Tungsten mining activity in 1991 remained at a level near that of 1990 as the continued low prices for concentrate prevented the reopening of any closed mines. Recent statistical trends in domestic mine shipments and their corresponding values are shown in figures 1 and 2, respectively. A list of major concentrate producers and those processing the various stages of intermediate tungsten materials are shown in table 3. Net production statistics for tungsten metal powders, carbides, and chemicals are shown in table 4.

Curtis Tungsten Inc., Upland, CA, owner and operator of the Andrew Tungsten Mine near Los Angeles, CA, resumed mining in January 1991 after the mine was closed for about 5 months because of a severe drought.

Curtis Tungsten and GTE Products Corp., Chemical and Metallurgical Div., Towanda, PA, signed a long-term contract effective August 1, 1991, enabling GTE to purchase an appreciable quantity of scheelite concentrates from Curtis's Andrew Mine. GTE produces a wide range of tungsten products, much of which are processed from the concentrates. The 42-month-long contract will provide for GTE to receive monthly up to 54 metric tons of contained tungsten at prices that will vary depending upon market conditions. As part of the contract, GTE advanced working capital to Curtis to progressively increase the output of the mine.

U.S. Tungsten Corp., Bishop, CA, continued as the only other company producing tungsten concentrate. The Pine Creek Mine and mill again was operated on an intermittent basis at levels below capacity to provide supplemental feedstock to the company's APT conversion facility. Imported concentrate was the primary source of raw material.

Canada Tungsten Mining Corp. Ltd. maintained its suspension on conversion of concentrate to APT at its Fort Madison, IA, facility during 1991. The company continued, however, during the year to supply its customers with products from its inventories.

Consumption and Uses

Total domestic consumption of tungsten in primary end-use categories (table 5) decreased by about 6% in 1991 compared with that of 1990. Demand for cemented carbides in the combined cutting tool, mining tool, oil drilling equipment, and wear-resistant component industries weakened during the last half of the year, ending with a decrease of about 4% compared with that of 1990. Demand for other tungsten products, including specialty steels, superalloys, chemicals, and mill products made from metal powder, also weakened during the final 6 months of the year, accounting for the remaining 2% decrease in demand for tungsten products.

Overall weakness in the U.S. economy was the single most important factor influencing the decline in demand for tungsten products during 1991. As the weakness in industrial sectors, such as auto, aerospace, construction, mining, and oil drilling progressively deepened, so also did the demand for cemented carbide and other hard-metal and alloy components used in these end-use sectors. The decline in demand for cemented carbide wear-resistant components was due, in part, to a progressive decrease in oil drilling activity following the cessation of the war in the Mideast in January 1991. As prices for crude oil rose during the war, the number of operating oil rigs in the United States rose sharply. After reaching a high of 1,179 on December 12, 1990, the number of rigs decreased to 797 by the end of 1991, according to figures reported by the International Association of Drilling Contractors and Baker Hughes Inc.

Markets and Prices

The average price for wolframite concentrates increased by 22% in 1991 while the average price for scheelite concentrates remained nearly unchanged, according to quotations published in Metal Bulletin (table 6). Wolframite prices progressively increased during the first three quarters of the year, then remained stable during the last quarter of

the year. Although scheelite prices were slightly higher in the last 5 months of the year, the average for the year was down about 1% compared with that of 1990.

Domestic APT prices increased steadily during the first 8 months of 1991, consistent with the rising prices for wolframite concentrates. According to quotations in Metals Week, APT prices ranged from \$66.14 to \$68.34 per (mtu) in January, rising to a range of \$84.88 to \$87.63 in mid-August. By yearend, prices had declined to a level of \$72.75 to \$73.85 per mtu. European APT prices were considerably lower than the domestic prices in 1991. Metals Week quotations for European APT were 11%, 23%, and 15% below the U.S. prices in the comparable months of January, August, and December, respectively. On July 1, 1991, Metals Week began publishing the price for APT from Hong Kong that reflected market transactions for #1 Grade APT from China. The Hong Kong prices essentially paralleled the European prices during the initial reporting period but by yearend was about 6% higher at \$64.00 to \$68.00 per mtu. Prices for tungsten metal powder and tungsten carbide powder remained virtually unchanged during the year, quoted at \$22.00 and \$21.65 per kilogram, respectively.

Effective January 1, 1991, the International Tungsten Indicator (ITI) was discontinued as a price index of trade in tungsten concentrates. The ITI prices, quoted since July 1978, were a reflection of international business activity in concentrates. Contributions to the quoted price were provided by both tungsten-consuming and tungsten-producing members of the ITI. Reasons for the discontinuance of the ITI were reported to include the fact that many of the original contributors to the ITI were no longer involved in trading concentrates, the number of producer members were reduced by the closure of many tungsten mines, and a shift toward the purchase of intermediate products rather than concentrates was made by some consumer members.

Foreign Trade

Comprehensive lists of U.S. export and import trade statistics by material quantity and value and by country of destination and origin are shown in tables 7 through 15. Import tariff rates for the various materials are shown in table 16.

Total U.S. imports of tungsten materials increased by 57% in 1991 compared with that of 1990. China continued to be the dominant supplier, providing about 46% of all imported tungsten materials. Although China's share of the U.S. tungsten imports was down about 4 percentage points from that of 1990, the total quantity of tungsten materials imported from China increased from 5,432 metric tons of contained tungsten in 1990 to 7,088 metric tons in 1991. Imports of concentrate from China decreased in 1991 because of China's decision to suspend new sales during the year and also because of the restrictions placed on these imports through implementation of an antidumping ruling. Subsequently, imports of intermediate tungsten products from China increased. The changing pattern of these imports was evident after mid-July when a conditional antidumping tariff of 151% was initially imposed on imports of concentrate. According to Bureau of the Census statistics, imports of concentrates from China during the first 7 months of 1991 totaled 3,091 metric tons of contained tungsten. During this same period, the combined imports of the intermediates APT, sodium tungstate, and tungsten oxides totaled 710 metric tons. In the subsequent 5 months following the imposition of the tariff, imports of concentrate essentially ceased, as was expected. Correspondingly, the imports of intermediates from China during the last 5 months of 1991 totaled 2,345 metric tons of contained tungsten. In comparison, intermediates imported from China during the same period in 1990 amounted to 548 metric tons of tungsten.

World Review

Capacity.—The data in table 17 are rated capacity for mines and mills as of

December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

Mine capacity for tungsten is based on published reports, maximum production statistics, and estimates. The latter is utilized particularly for certain countries where capacity information is either incomplete or unavailable. Estimated annual mine production capacity increased by about 5% in 1991 compared with that of 1990. Recent production statistics and estimates indicated higher capacities in Bolivia, China, and Peru. These capacities were offset partially by estimated lower capacities in Burma, the Republic of Korea, and the former U.S.S.R.

Canada.—Novagold Resources, Canada, reportedly signed a letter of intent in early 1991 to purchase the Mount Pleasant Tungsten Mine, New Brunswick, from its joint owners, Billiton Metals Ltd., Canada, and Lac Minerals, Canada. Payment for the interest in the mine and its assets will be through net profit royalties resulting from the operation of the mine. Novagold, in turn, will exempt Billiton and Lac from any future environmental liabilities in connection with ownership and operation of the facilities. Although no decision was made by Novagold on when production would begin at the mine, one source speculated that it would be operated initially for recovery of its tin value. Underground reserves at the Mount Pleasant Mine consist of an estimated 36,000 metric tons of tungsten, 35,000 metric tons of tin, and 18,000 metric tons of molybdenum.

Annual concentrate production and consumption statistics for the world are shown in tables 18 and 19, respectively.

China.—New plans, rules, and policies affecting China's production and trade of tungsten products reportedly were implemented by the Chinese Government on January 1, 1991. These included reducing concentrate production by 30%, suspending exports of concentrate for a minimum of 6 months, and abolishing export subsidies on all tungsten materials. The latter action, according to some industry analysts, could shut down as many as 50 to 60 small, uneconomical tungsten-producing and tungsten-processing operations. A spokesman for China's Ministry of Foreign Economic Relations and Trade further stated that the suspension of exports of concentrate would remain in effect until a realignment of its tungsten mining industry was completed.

Subsequent to the preceding actions, the State Council, China's highest governing body, listed tungsten, along with three other resources, in a category to receive State protection. The State Council ordered the State Planning Commission, with the help of the China National Nonferrous Metals Industry Corp., to work out a plan for the medium- and long-term utilization of these resources. According to the Council's directive, mining as well as processing of these resources would be carried out through state-owned operations, although in select cases collectively owned operations would be allowed.

In additional efforts to restructure and further control the tungsten industry, the Chinese State Council issued a policy forbidding the construction of any new plants for production of APT and other intermediate tungsten materials. As part of this policy, announced late in the third quarter of 1991, all of the small, inefficient processing facilities would be closed. Only a few of the larger, more efficient and competitive plants would be protected in order to control the quantity and quality of the materials effectively.

European Community (EC).—During 1991, imports of tungsten concentrate, tungstic acid and oxide, and tungsten carbide powder and fused tungsten carbide from China continued to be subject to duties of 42.4%, 35%, and 33%, respectively. The alternative minimum price standards also remained in effect for specific exporters, China National Nonferrous Metals Import and Export Corp. (CNIEC), and China National Minerals and Metals Import and Export Corp. By yearend, EC officials reported that they were in the process of reviewing the established minimum price standards to determine their effectiveness. The undisclosed standards, particularly the one agreed upon for concentrate, remained a subject of speculation by industry analysts. A price of \$68.00 per mtu WO₃ reportedly was considered to be a feasible probability. The average price for wolframite concentrates was about \$46.00 as quoted in Metal Bulletin (London) during 1990 when the standards were established.

Hungary.—Tungfram Co. Ltd., a manufacturer of tungsten for lamp and lighting end-use products, disclosed that General Electric Co., Euclid, OH, had increased its share in the company to 75% from the previous 50%. As General Electric increased its interest in the European lighting market, Tungfram, in turn, was reported to be expanding its interest into the Mideast. By yearend, discussions with Saudi Arabian officials were nearing a final agreement that would allow for construction of a lighting factory in the eastern part of Saudi Arabia.

India.—Production of tungsten concentrate in India was expected to increase appreciably as a result of a decision in early 1991 to transfer the operation of the Degana Tungsten Mine from Rajasthan State Tungsten Development Corp. to Hindustan Zinc. The Degana Mine is in the Nagore district of the State of Rajasthan and has yielded up to 20 metric tons of tungsten in concentrate annually. According to a

report in India's Minerals and Metals Review, the added investment by Hindustan in the mine was projected to raise the annual output of the mine to 330 metric tons of tungsten. The action taken at Degana was part of an overall expansion plan for India's tungsten industry to support the anticipated doubling of the country's demand for tungsten products by the year 2000.

International Tungsten Industry Association (ITIA).—In April 1991, CNIEC rejoined the ITIA. Although no official reason was given for this decision, industry analysts speculated that it was related to policy changes within China affecting the production and marketing of their tungsten products. After being an original member of the ITIA in 1988, CNIEC left the organization in 1989. The official reason given at that time for its departure was that the ITIA, being essentially an industry, consumer-based association, already had one of its subsidiaries, Zhuzhou Cemented Carbide as a member.

Italy.—Under new guidelines set forth in a National Mining Policy Law in July 1991, tungsten was included among a group of metals regarded as essential to the country's economy. In addition, tungsten was listed as a priority metal eligible for funding of mine exploration outside of the country. Exploration projects that will receive preference will be those that increase the security of supply and stabilize prices while still being compatible with continuing domestic production.

Portugal.—Beralt Tin and Wolfram Ltd. signed an agreement with General Electric Co., Euclid, OH, in mid-1991 to provide the latter company with specified quantities of tungsten concentrate over a 5-year period beginning in 1992. Through its Portuguese subsidiary, Beralt owns 80.55% of the Panasqueira Tungsten Mine near Fundao. A 75% share of Beralt was purchased by Minorco SA, Portugal, from Charter Consolidated Ltd., United Kingdom, in

October 1990. The agreement will permit General Electric to purchase a significant portion of Beralt's annual production of wolframite concentrate at undisclosed fixed rates as well as varying market rates.

At the beginning of 1991, Minorco officials announced plans for a mine-deepening program at Panasqueira that will allow access to additional tungsten reserves 60 meters below the present lowest level. The program was expected to be completed in about 1 year, although no specific time was indicated for it to be initiated.

Spain.—Efforts continued during 1991 to reopen the La Parilla Tungsten Mine in Extremadura Province. Spanish labor unions again voiced their desire to have the mine reopened, pointing to the fact that, in addition to providing employment in the largely rural province, it would be the sole source of scheelite concentrate within the European Community. The owners of the mine, Banco de Credito Industrial and Banco Espanol de Credito, reportedly provided reinforcement to the efforts to reopen the mine by applying for subsidies from the Spanish Economy Ministry's Regional Development Commission.

United Nations Conference on Trade and Development (UNCTAD).—The UNCTAD Committee on Tungsten (COT) convened its 23d session in Geneva, Switzerland, in November 1991. During the discussions of the Sessional Working Group, a presentation by a representative from the UNCTAD Secretariat's office provided an overview of the status of the world tungsten industry. Estimates of world consumption and production of tungsten ore concentrates continued to show a statistical surplus of supply over demand. Economic slowdowns in the world's major economies were expected, in the short term, to exercise a negative influence on both trade and prices in the tungsten market. Several delegations voiced their agreement with this analysis in their prepared market statements. Some commented further that the market

also was complicated by the fact that, in certain markets, the value-added intermediates were being sold at essentially the same price as the ore concentrates. Concerns also were expressed by certain delegations over the increasing use of protectionism in the market, citing as examples the recent U.S. and European Commission (EC) import relief measures against China. China, in its market statement, assessed the world supply-demand imbalance in tungsten as being caused only by the sluggish demand in major consuming countries and not by overproduction.

The need to improve transparency in the UNCTAD statistics was expressed repeatedly during the meeting. Comments by the former U.S.S.R.'s delegation indicated that statistics, particularly those from the Republic of Russia, would be improved in the near future. According to the information available at the time of the meeting, the delegates expected to be able to provide some recent production and consumption data from the Russian Republic in time for the 1992 meeting. Data on imports of tungsten materials were not expected to be available. Although exports of tungsten materials were insignificant and thus did not influence the market, data on such trade activity were expected to be available should appreciable quantities of tungsten be exported in the future.

In a continued effort to promote greater industry participation in the COT, two technical discussions were presented by industry representatives. The first, by Dr. Zhengji Tao, of Zhuzhou Cemented Carbide Works, China, provided a 10-year overview of research and development (R & D) activity in tungsten metal and tungsten carbide powder. The second, by Dr. W. D. Schubert, of the Chemical Technology Institute, Austria, provided information on current trends and R & D activities in materials technology as it relates to tungsten and tungsten alloys and the possible impact these activities will have on the end-user market.

The issue of market stabilization received very little discussion during the meeting but was retained as an item on

the provisional agenda for the next meeting.

Based upon discussions held during the previous session of the COT, the COT sought and was awarded designation as an International Commodity Body (ICB). This provided access to the account for funding developmental activities within the Common Fund under UNCTAD. As a result, a separate item was added to the provisional agenda for this 23d session to consider project proposals for submission and possible financing under this account. The UNCTAD Secretariat representative prefaced the discussion on project proposals with a brief overview of information obtained while attending an ICB instructional seminar in September 1991. The Secretariat's presentation offered valuable incites toward achieving efficient and effective methods of utilizing the resources from the Common Fund. Procedures and criteria were established for the appraisal of projects for submission to the Common Fund. The basic language of this document was derived from one prepared by another ICB, The International Cotton Advisory Committee. In addition, language was included ensuring that no financial obligations would accrue to the COT as a result of any project, nor would any liability be incurred on individual members of the COT in association with the funding of such project.

Three project proposals relating to improving methods for the production of cemented carbides were submitted by the delegation from China. The Secretary-General of the International Tungsten Industry Association, representing its members, presented several research ideas for possible expansion to project proposal form. These included the extension of testing programs to improve health and safety in the tungsten work environment and the acceleration of efforts to find new uses for tungsten-containing materials, for example, as catalysts, corrosion inhibitors, pigments, and electrical conductor materials.

According to the adopted procedures and criteria, none of the proposed projects from China was deemed ready for a decision by the COT toward a

funding recommendation. Some specific questions were presented by UNCTAD that pertained to the financial contribution by China to the projects and the potential participation by other countries in the projects. It was agreed that the other delegations would provide written comments on China's proposals through the UNCTAD Secretariat's office by January 31, 1992. Based on these comments, China would be required to submit its revised versions to the Secretariat by February 29, 1992. The revised versions would then be considered at an ad hoc meeting to be held in May or June 1992. Any other proposals submitted 4 months prior to the convening of the ad hoc committee would also be considered at that time.

Current Research

Several studies relating to the high-velocity-oxy-fuel (HVOF) thermal spraying method for applying tungsten carbide-cobalt (WC-Co) coatings were reported during 1991. An important characteristic of the process is that it effectively spreads the sprayed particles into a denser and more wear-resistant coating than is possible using alternative spraying processes such as plasma spraying. It has been used on gas-turbine aircraft engine components, including compressor vanes and blades, bearing housings, and shrouds. In recent studies, HVOF coated WC-Co deposits were produced having a superior wear-resistant, mirror-finished surface comparable to the lapped surface roughness of cemented tungsten carbide.¹ Results of other research showed that the HVOF process yielded WC-Co coatings with excellent machinability and abrasive strength that exhibited good cohesive strength and low internal stress levels.² Sliding wear tests performed on these WC-12Co coatings on steel demonstrated excellent coating properties and wear performance. Similar satisfactory results were obtained in wear tests on coatings prepared by a high-energy plasma process.³

Modifications to existing cemented carbide technology also were investigated

in order to improve the performance of cemented carbide end-use items. The addition of self-lubricating, hexagonal boron nitride powder to WC-6.5Co powder improved the sliding-wear resistance of the resulting sintered material when compared to conventional cemented carbide material under dry, sliding test conditions.⁴ This improved performance was expected to be applied beneficially in bearing materials and mechanical seal devices. In another research effort, use of ultrafine WC powder enabled the production of corrosion and wear-resistant carbide parts without the incorporation of a Co binder.⁵ Satisfactory mechanical and chemical properties were evident in molds and mechanical seal parts prepared from this binderless material. Further research also showed that the mechanical and thermal shock properties of Co-bonded WC parts could be improved by the addition of metallic particles to the WC-Co composite.⁶ For example, increased fracture toughness was achieved in hot pressed and sintered WC-10Co composites that had been interspersed with molybdenum and niobium particles. Indentation techniques used to measure crack growth resistance and to study the crack-particle interactions in these composites showed that crack growth was impeded specifically by large niobium particles.

During 1991, research efforts also focused on evaluating the applicability of certain tungsten-containing materials to specific space technology systems. Using a tungsten metal-lithium hydride radiation shield material, optimum shield design was determined for a nuclear thermal propulsion system.⁷ With this design, the radiation incident upon all components of the propulsion system, as well as the electronic control system, was able to be maintained within the acceptable limits required for reliable and safe space mission operations. Other researchers also reported on the unique advantage of using a tungsten-fiber-reinforced niobium matrix composite for space power system applications.⁸ Specifically, this composite was considered as component material in the fuel containment and structural

support systems. A related space technology study included determinations of the feasibility of using certain tungsten-base alloys as high-temperature materials in both thermal and electric nuclear propulsion systems.⁹

Results of investigations reported by several researchers indicated improvement in the quality of plasma sprayed WC-Co coatings. In one study, plasma sprayed coatings sealed with a nickel-phosphorus alloy by electroless plating and pressed isostatically at 600° to 1,000° C and pressures of 0.9 to 5.0 mega Pascals exhibited superior wear-resistance compared with the as-sprayed coatings.¹⁰ In another study, researchers reported that a post-deposition-heat-treatment/quenching procedure revealed improved adhesion of plasma sprayed WC-Co coatings to a steel substrate.¹¹ This was achieved through increased metallurgical bonding at the coating-substrate interface. Use of the heat-treatment/quenching method also resulted in a significant increase in the hardness of the WC-Co coatings. In subsequent bend and impact tests, the heat-treated coatings exhibited beneficial residual compressive stress. Abrasive wear tests showed enhanced durability of the coatings and improved wear performance compared to coatings not subjected to a post-deposition-heat-treatment/quenching procedure. In an additional study, the quality of WC-Co coatings produced with a high-velocity plasma spray process (Gator Gard) was enhanced by conducting the spraying procedure in a low-pressure inert environment.¹² This vacuum plasma spray (VPS) deposition process significantly increased the hardness of the coating and extended the practical spray distance by up to 5 times more than was possible when the high-velocity spray process was conducted in air.

A new method for production of an ultrafine (0.05 micrometer) WC powder was reported by researchers during the year.¹³ Carburization of the tungsten was achieved during a 10-minute reaction period in a microwave-induced carbon monoxide plasma, yielding 99.96% WC particles containing 0.04% free carbon. In addition to producing finer WC

particles, the process was significantly less energy intensive than that of conventional processes in which the WC is synthesized from the elements. The demand for submicron WC powder continued to increase in response to the need for the harder, stronger, and more impact resistant cutting and wear-resistant cemented carbide components that can be produced with the finer powder.

An advanced semiconductor production method using chemically vapor-deposited tungsten as the wiring medium was reported during the year.¹⁴ If proven successful, the new method reportedly could be employed to produce computer chips with 64 times greater memory capacity than the most advanced chips now in production.

OUTLOOK

Based upon apparent consumption data accumulated during the first half of 1992, the total annual demand for tungsten materials in the United States in 1992 was estimated to be about 9,600 metric tons of contained tungsten. This would represent a decline in apparent consumption of approximately 5% compared with that of 1991. According to industry reports, a slow economic recovery in 1992 would continue to hold down the demand for tungsten in key sectors such as metalcutting and metalworking but modest growth could be expected in certain specialty carbide sectors as well as mining and construction equipment. In addition to the effect of economic factors, any growth in tungsten demand will continue to be buffered by the effects of substitution in the cutting and wear-resistant component industries as well as by technological improvements within the industry that result in more efficient use of tungsten.

The changing political philosophies in the former U.S.S.R. and Eastern Europe will effectively decrease the world demand for tungsten in the short term as the transition from militarized to industrialized economies occurs.

Supplies of tungsten concentrate and intermediate materials for U.S. consumption are expected to be sufficient

in 1992 in spite of the continued lack of production of concentrates at domestic tungsten mines. The increase in consumer stocks of concentrate, imported during 1991, as well as the apparent oversupply of concentrates and intermediate tungsten products on the world market, will likely continue to serve the U.S. tungsten needs well into 1993.

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TABLE 1
SALIENT TUNGSTEN STATISTICS

(Metric tons of tungsten content unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Concentrate:					
Mine production	34	W	W	W	W
Mine shipments	34	W	W	W	W
Value	thousands	\$216	W	W	W
Consumption	5,506	7,832	7,725	¹ 5,878	¹ 5,309
Shipments from Government stocks	708	524	466	—	—
Exports	2	172	203	139	21
Imports for consumption	4,414	8,045	7,896	6,420	7,837
Stocks, December 31:					
Producer	21	21	10	¹ 16	26
Consumer	329	499	1,261	1,077	1,778
Ammonium paratungstate:					
Production	5,336	8,357	7,831	¹ 6,142	¹ 5,448
Consumption	6,363	8,014	8,493	8,787	² 8,897
Stocks, December 31: Producer and consumer	292	1,016	915	896	578
Primary products:					
Production	7,424	8,068	8,749	³ 4,677	8,980
Consumption	7,228	8,298	7,990	8,496	7,981
Stocks, December 31:					
Producer	1,646	1,890	1,562	⁴ 1,459	⁴ 1,667
Consumer	787	930	761	⁴ 793	796
World: Concentrate:					
Production	42,474	⁵ 1,224	⁵ 1,609	⁵ 1,918	⁵ 2,960
Consumption	⁶ 44,378	⁶ 50,155	⁶ 49,865	⁶ 38,216	⁶ 36,689

⁶Estimated. ⁷Revised. W Withheld to avoid disclosing company proprietary data.

¹Excludes 2 months of "withheld" data.

²Excludes 1 month of "withheld" data.

³Includes only hydrogen-reduced metal powder and chemicals.

⁴Excludes tungsten carbide-cast and crystalline.

TABLE 2
U.S. GOVERNMENT TUNGSTEN STOCKPILE MATERIAL INVENTORIES
AND GOALS

(Metric tons of tungsten content)

Material	Inventory by program, December 31, 1991			
	Goals	National stockpile	DPA ¹ inventory	Total
Tungsten concentrate:				
Stockpile-grade	35,938	24,504	72	24,576
Nonstockpile-grade	—	10,055	5	10,060
Total	35,938	34,559	77	34,636
Ferrotungsten:				
Stockpile-grade	—	385	—	385
Nonstockpile-grade	—	533	—	533
Total	—	918	—	918
Tungsten metal powder:				
Stockpile-grade	726	711	—	711
Nonstockpile-grade	—	150	—	150
Total	726	861	—	861
Tungsten carbide powder:				
Stockpile-grade	907	871	—	871
Nonstockpile-grade	—	51	—	51
Total	907	922	—	922

¹Defense Production Act (DPA) of 1950.

TABLE 3
MAJOR PRODUCERS OF TUNGSTEN CONCENTRATE AND PRINCIPAL
TUNGSTEN PROCESSORS IN THE UNITED STATES IN 1991

Company	Location of mine, mill, or processing plant
Producers of tungsten concentrate:	
Curtis Tungsten Inc.	Upland, CA.
U.S. Tungsten Corp., a division of Strategic Minerals Corp.	Bishop, CA.
Processors of tungsten:	
Buffalo Tungsten Inc.	Depew, NY.
Canada Tungsten Mining Corp. Ltd.	Fort Madison, IA.
General Electric Co.	Euclid, OH.
GTE Products Corp.	Towanda, PA.
Kennametal Inc.	Latrobe, PA, and Fallon, NV.
Teledyne Firth Sterling	La Vergne, TN.
Teledyne Wah Chang Huntsville	Huntsville, AL.
U.S. Tungsten Corp., a division of Strategic Minerals Corp.	Bishop, CA.

TABLE 4
NET PRODUCTION¹ AND STOCKS OF TUNGSTEN PRODUCTS
IN THE UNITED STATES IN 1991

(Metric tons of tungsten content)

	Tungsten carbide powder			Chemicals	Total ²
	Hydrogen-reduced metal powder	Made from metal powder	Cast and crystalline		
Net production	5,616	3,364	W	W	8,980
Producer stocks, December 31, 1991	918	550	W	199	1,667
Producer stocks, December 31, 1990	778	503	W	178	1,459

W Withheld to avoid disclosing company proprietary data.

¹Gross production less quantity used to make other products in table.

²Excludes "withheld" data.

TABLE 5
CONSUMPTION AND STOCKS OF TUNGSTEN PRODUCTS IN THE UNITED STATES IN 1991, BY END USE

(Metric tons of tungsten content)

End use	Ferrotungsten ¹	Tungsten metal powder	Tungsten carbide powder	Tungsten scrap ²	Other tungsten materials ³	Total ⁴
Steel:						
Stainless and heat-resisting	44	—	—	W	W	44
Alloy	W	—	—	—	—	W
Tool	243	—	—	W	—	243
Superalloys	13	W	44	230	W	287
Alloys (excludes steels and superalloys):						
Cutting and wear-resistant materials	—	86	4,715	W	W	4,801
Other alloys ⁵	W	7	W	W	—	7
Mill products made from metal powder	—	1,941	W	—	W	1,941
Chemical and ceramic uses	—	—	—	—	44	44
Miscellaneous and unspecified	146	26	10	273	159	614
Total⁴	445	2,060	4,769	502	203	7,981
Consumer stocks, December 31, 1991	42	24	644	50	36	796

W Withheld to avoid disclosing company proprietary data; included in "Miscellaneous and unspecified."

¹Includes scheelite, natural and synthetic.

²Does not include that used in making primary tungsten products.

³Includes tungsten chemicals and others.

⁴Data may not add to totals shown because of independent rounding.

⁵Includes welding and hard-facing rods and materials and nonferrous alloys.

⁶Based on reported consumption plus information from secondary sources on companies not canvassed; includes estimates.

TABLE 6
MONTHLY PRICE QUOTATIONS OF TUNGSTEN CONCENTRATE IN 1991

Month	Metal Bulletin (London), scheelite European market, 70% WO ₃ basis ¹			Metal Bulletin (London), wolframite, European market, 65% WO ₃ basis ²			Metals Week, U.S. spot quotations, 65% WO ₃ basis, c.i.f. U.S. ports ³					
	Dollars per metric ton unit		Dollars per short ton unit	Dollars per metric ton unit		Dollars per short ton unit	Dollars per short ton unit		Dollars per metric ton unit			
	Low	High	Average	Low	High	Average	Average	Low	High	Average	Average	
January	52.00	71.00	61.50	55.80	37.00	50.00	44.16	40.07	32.00	46.00	39.80	43.88
February	52.00	71.00	61.50	55.80	42.00	51.00	47.75	43.32	44.00	48.00	46.00	50.71
March	52.00	71.00	61.50	55.80	45.00	55.00	48.54	44.04	44.00	55.00	47.63	52.51
April	52.00	71.00	61.50	55.80	50.00	60.00	53.69	48.71	52.00	61.00	57.00	62.84
May	52.00	71.00	61.50	55.80	50.00	60.00	56.38	51.15	55.00	61.00	58.00	63.94
June	52.00	71.00	61.50	55.80	54.00	60.00	57.00	51.71	55.00	67.00	59.38	65.46
July	52.00	71.00	61.50	55.80	54.00	60.00	57.89	52.52	56.00	65.00	61.00	67.24
August	52.00	71.00	62.25	56.48	56.00	67.00	61.25	55.57	58.00	65.00	61.70	68.02
September	55.00	71.00	63.00	57.16	59.00	67.00	63.00	57.16	60.00	65.00	62.50	68.90
October	55.00	71.00	63.00	57.16	59.00	67.00	63.00	57.16	59.00	65.00	62.13	68.49
November	55.00	71.00	63.00	57.16	59.00	67.00	63.00	57.16	55.00	59.00	57.00	62.84
December	55.00	71.00	63.00	57.16	59.00	67.00	63.00	57.16	55.00	59.00	57.00	62.84

¹Low and high prices are reported semiweekly. Monthly averages are arithmetic averages of semiweekly low and high prices. The average price per metric ton unit of WO₃, which is an average of all semiweekly low and high prices, was \$62.06 for 1991. The average equivalent price per short ton unit of WO₃, was \$56.30 for 1991.

²Low and high prices are reported semiweekly. Monthly averages are arithmetic averages of semiweekly low and high prices. The average price per metric ton unit of WO₃, which is an average of all semiweekly low and high prices, was \$56.56 for 1991. The average equivalent price per short ton unit of WO₃, was \$51.31 for 1991.

³Low and high prices are reported weekly. Monthly averages are arithmetic averages of weekly low and high prices. The average price per short ton unit of WO₃, which is an average of all weekly low and high prices, excluding duty, was \$55.76 for 1991. The average equivalent price per metric ton unit of WO₃, was \$61.46 for 1991.

TABLE 7
U.S. EXPORTS OF TUNGSTEN ORE AND CONCENTRATE, BY COUNTRY

Country	1990		1991	
	Tungsten content ¹ (metric tons)	Value (thousands)	Tungsten content ² (metric tons)	Value (thousands)
Australia	—	—	4	\$34
Austria	60	\$334	1	10
Belgium	10	56	—	—
Germany, Federal Republic of	9	47	—	—
Hong Kong	1	6	—	—
Mexico	6	31	2	17
Peru	10	57	—	—
Singapore	42	234	—	—
United Kingdom	—	—	13	103
Total ³	139	765	21	165

¹Calculated based upon an estimated value of \$44 per metric ton unit WO₃.

²Calculated based upon an estimated value of \$61 per metric ton unit WO₃.

³Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 8
U.S. EXPORTS OF AMMONIUM PARATUNGSTATE, BY COUNTRY

Country	1990		1991	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Canada	—	—	(¹)	(¹)
Denmark	1	\$10	—	—
France	48	270	—	—
Hungary	10	73	10	\$73
Japan	159	1,047	535	2,856
Netherlands	—	—	2	12
Sweden	—	—	170	879
United Kingdom	138	1,056	54	294
Total ²	356	2,456	770	4,114

¹Less than 1/2 unit.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 9
U.S. EXPORTS OF TUNGSTEN CARBIDE POWDER, BY COUNTRY

Country	1990		1991	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Argentina	(¹)	\$9	(¹)	\$15
Australia	90	570	3	104
Austria	52	919	48	808
Belgium	9	276	57	1,007
Brazil	6	178	2	74
Canada	221	4,134	249	5,473
Chile	(¹)	3	(¹)	3
China	2	59	—	—
Colombia	—	—	(¹)	5
Czechoslovakia	—	—	(¹)	8
Denmark	39	454	19	234
Finland	3	74	3	77
France	33	1,150	21	389
Germany, Federal Republic of	150	3,573	123	3,328
Hong Kong	1	20	—	—
India	(¹)	6	—	—
Ireland	(¹)	29	1	35
Israel	—	—	3	268
Italy	118	3,240	48	1,612
Japan	47	817	55	1,064
Korea, Republic of	1	67	1	44
Luxembourg	11	244	13	320
Malaysia	(¹)	3	—	—
Mexico	22	768	5	268
Netherlands	18	707	8	323
Singapore	2	86	2	100
South Africa, Republic of	—	—	32	385
Spain	50	772	—	—
Sweden	75	1,197	16	206
Switzerland	49	1,071	15	741
Taiwan	5	116	5	144
Turkey	—	—	(¹)	11
United Kingdom	67	1,295	107	1,820
Venezuela	1	39	1	17
Other	2	69	—	—
Total²	1,074	21,946	839	18,880

¹Less than 1/2 unit.

²Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 10
U.S. EXPORTS OF TUNGSTEN AND TUNGSTEN ALLOY POWDER, BY COUNTRY

Country	1990			1991		
	Gross weight (metric tons)	Tungsten content ¹ (metric tons)	Value (thousands)	Gross weight (metric tons)	Tungsten content ¹ (metric tons)	Value (thousands)
Australia	8	7	\$124	2	1	\$25
Austria	48	39	762	1	1	45
Belgium	2	2	87	4	3	140
Brazil	7	5	192	8	6	225
Canada	50	40	1,580	37	30	1,037
Finland	3	3	75	2	1	81
France	6	4	171	10	8	440
Germany, Federal Republic of	209	167	5,468	135	108	3,542
Hong Kong	3	2	23	(²)	(²)	27
India	20	16	284	—	—	—
Israel	132	105	1,125	234	188	2,819
Italy	15	12	716	19	15	1,051
Japan	21	17	531	12	10	428
Korea, Republic of	1	1	41	31	25	134
Mexico	5	4	162	8	7	166
Netherlands	544	435	4,757	193	155	1,445
Pakistan	45	36	669	44	35	581
Singapore	1	1	37	16	13	243
South Africa, Republic of	2	2	50	1	1	20
Spain	2	1	50	—	—	—
Sweden	4	3	21	2	1	72
Switzerland	6	5	334	1	1	55
Taiwan	16	13	415	32	26	381
Turkey	2	2	54	3	2	77
United Kingdom	82	66	832	62	49	825
Other	1	(²)	27	3	3	90
Total	1,235	988	18,587	861	689	13,947

¹Tungsten content estimated by multiplying gross weight by 0.80.

²Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 11
U.S. EXPORTS OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1990		1991	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Tungsten and tungsten alloy wire:				
Argentina	(¹)	\$12	(¹)	\$5
Belgium	(¹)	10	1	102
Brazil	7	486	7	490
Canada	21	1,701	24	2,143
Colombia	—	—	1	261
France	3	300	3	383
Germany, Federal Republic of	1	400	1	308
Hong Kong	1	107	1	152
India	21	1,270	21	1,369
Italy	7	706	4	469
Japan	10	1,217	7	1,010
Korea, Republic of	2	228	5	352
Mexico	4	431	3	297
Netherlands	1	211	1	143
Poland	1	57	1	60
Switzerland	(¹)	71	(¹)	101
Taiwan	5	435	4	293
United Kingdom	1	240	2	423
Venezuela	(¹)	5	—	—
Other	5	380	5	486
Total²	90	8,267	93	8,848
Unwrought tungsten and alloy in crude form, waste and scrap:				
Australia	4	67	5	96
Austria	9	222	—	—
Belgium	1	36	(¹)	11
Canada	7	184	8	198
Chile	4	112	7	212
France	(¹)	3	1	15
Germany, Federal Republic of	250	4,893	202	3,227
Israel	34	805	39	910
Japan	16	206	20	229
Korea, Republic of	2	91	(¹)	13
Mexico	—	—	40	955
Spain	—	—	35	834
Sweden	33	464	6	123
Taiwan	8	205	7	198
United Kingdom	26	401	12	281
Other	24	519	8	202
Total²	418	8,208	391	7,503
Other tungsten metal:				
Australia	6	330	1	216
Austria	5	247	(¹)	24
Belgium	(¹)	10	—	—

¹ footnotes at end of table.

TABLE 11—Continued
U.S. EXPORTS OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1990		1991	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Other tungsten metal—Continued				
Brazil	2	\$161	2	\$142
Canada	20	1,103	4	229
Colombia	—	—	1	164
France	2	139	1	188
Germany, Federal Republic of	20	984	4	331
Hong Kong	(¹)	29	1	107
India	3	182	1	28
Ireland	38	5,699	55	9,004
Italy	8	675	1	149
Japan	50	5,077	13	3,063
Korea, Republic of	11	744	5	952
Mexico	4	426	8	725
Netherlands	1	117	1	274
Singapore	2	141	1	115
South Africa, Republic of	1	60	1	55
Spain	3	214	1	42
Sweden	1	138	2	181
Switzerland	(¹)	39	1	67
Taiwan	6	519	11	895
Thailand	1	89	1	69
United Kingdom	42	2,078	13	888
Venezuela	1	70	(¹)	22
Other	15	483	2	208
Total²	242	19,753	130	18,135
Ferrotungsten and ferrosilicon tungsten:				
Canada	2	25	13	115
Indonesia	4	14	—	—
Mexico	17	45	19	45
Venezuela	2	14	—	—
Total²	25	98	32	161
Wrought tungsten:³				
Australia	—	—	(¹)	32
Canada	—	—	45	2,127
France	—	—	5	249
Germany, Federal Republic of	—	—	5	227
India	—	—	2	82
Israel	—	—	17	49
Japan	—	—	29	1,299
Mexico	—	—	10	119
Singapore	—	—	1	46
Spain	—	—	3	136
United Kingdom	—	—	4	210
Venezuela	—	—	2	77

See footnotes at end of table.

TABLE 11—Continued
U.S. EXPORTS OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1990		1991	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Wrought tungsten—Continued				
Other	—	—	4	\$273
Total²	—	—	127	4,926
Other tungsten compounds:⁴				
Argentina	—	—	2	23
Belgium	(¹)	4	—	—
Canada	1	7	5	28
France	1	15	(¹)	118
Germany, Federal Republic of	2	29	—	—
Israel	—	—	(¹)	7
Japan	—	—	18	107
Mexico	(¹)	3	—	—
Singapore	(¹)	181	—	—
United Kingdom	15	118	23	182
Total²	20	357	49	464

¹Less than 1/2 unit.

²Data may not add to totals shown because of independent rounding.

³Included in category "other tungsten metal" in 1990.

⁴Includes only other tungstates.

Source: Bureau of the Census.

TABLE 12
U.S. IMPORTS FOR CONSUMPTION OF TUNGSTEN ORE AND CONCENTRATE, BY COUNTRY

Country	1990		1991	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Australia	11	\$32	216	\$1,390
Belgium	—	—	4	27
Brazil	—	—	79	485
Bolivia	1,061	4,613	1,170	6,735
Burma	31	148	305	2,067
Canada	106	1,112	—	—
China	3,964	18,847	3,185	16,031
France	—	—	14	87
Germany, Federal Republic of	12	52	—	—
Hong Kong	44	284	124	663
Japan	—	—	28	178
Kenya	—	—	12	50
Korea, Republic of	—	—	6	40
Malaysia	—	—	11	70
Mexico	136	634	148	953
Netherlands	29	138	22	131
Peru	744	3,800	1,052	5,417
Portugal	120	691	828	5,193
Rwanda	162	950	148	840
Singapore	—	—	13	73
South Africa, Republic of	—	—	52	218
Spain	—	—	33	301
Thailand	—	—	378	2,272
Uganda	—	—	8	48
Total ¹	6,420	31,301	17,837	43,269

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 13
U.S. IMPORTS FOR CONSUMPTION OF AMMONIUM
PARATUNGSTATE, BY COUNTRY

Country	1990		1991	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
China	413	\$3,011	667	\$5,474
Germany, Federal Republic of	49	452	24	165
Hong Kong	—	—	28	213
Korea, Republic of	—	—	48	435
Netherlands	—	—	26	154
Sweden	—	—	18	122
United Kingdom	—	—	30	193
Total ¹	462	3,463	842	6,756

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 14
U.S. IMPORTS FOR CONSUMPTION OF FERROTUNGSTEN, BY
COUNTRY

Country	1990		1991	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Australia	13	\$90	—	—
Belgium	9	51	—	—
Canada	—	—	12	\$74
China	455	2,455	506	3,014
Germany, Federal Republic of	1	5	—	—
Hong Kong	13	74	—	—
Mexico	—	—	8	40
United Kingdom	2	63	—	—
Total ¹	493	2,739	525	3,128

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 15
U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1990		1991	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Waste and scrap:				
Australia	13	\$43	7	\$35
Austria	—	—	12	100
Belgium	—	—	39	278
Brazil	—	—	40	184
Canada	30	308	19	139
China	99	697	205	1,687
France	7	29	50	349
Germany, Federal Republic of	15	422	714	4,427
Hong Kong	1	10	—	—
Israel	180	1,039	55	260
Italy	8	17	—	—
Japan	253	1,205	454	2,401
Korea, Republic of	25	92	228	813
Mexico	8	73	14	96
Netherlands	311	2,585	178	865
Singapore	45	281	40	391
South Africa, Republic of	47	259	96	577
Sweden	7	13	19	98
Switzerland	4	4	—	—
United Kingdom	27	304	232	1,253
Other	—	—	35	187
Total¹	1,080	7,381	2,435	14,141
Unwrought tungsten, except alloys, in lump, grains, and powders:				
Belgium	5	191	5	205
Canada	11	368	11	443
China	5	117	37	597
Germany, Federal Republic of	25	759	14	372
Japan	10	323	18	774
Netherlands	25	194	—	—
Sweden	17	654	—	—
Thailand	14	65	—	—
United Kingdom	58	658	46	542
Other	(²)	9	1	9
Total¹	170	3,338	132	2,943
Unwrought tungsten-ingots, shot, alloys and other:				
Austria	4	177	4	100
Belgium	—	—	30	160
China	7	152	4	91
Germany, Federal Republic of	—	—	1	12

See footnotes at end of table.

TABLE 15—Continued
U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1990		1991	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Other	1	33	1	16
Total	12	362	40	380
Wrought tungsten-wire, plate, sheet, strip, foil, and other: ²				
Austria	15	\$2,089	15	\$1,932
Belgium	3	376	(³)	125
China	(³)	16	(³)	13
France	(³)	13	(³)	10
Germany, Federal Republic of	4	775	9	1,428
Israel	—	—	30	1,853
Japan	82	12,369	82	11,921
Korea, Republic of	(³)	2	1	3
Mexico	7	1,205	12	2,586
Netherlands	2	358	3	345
U.S.S.R.	—	—	26	281
United Kingdom	10	426	4	154
Other	11	378	4	592
Total ¹	135	18,008	184	21,244
Calcium tungstate:				
Australia	—	—	2	11
Germany, Federal Republic of	4	163	3	173
Spain	—	—	14	74
Total	4	163	19	258
Tungsten oxides:				
China	341	2,895	1,360	10,669
Germany, Federal Republic of	2	19	36	234
Hong Kong	—	—	182	1,139
Italy	—	—	(³)	11
Korea, Republic of	—	—	45	321
Netherlands	—	—	54	302
United Kingdom	(³)	2	(³)	2
Total ¹	343	2,916	1,678	12,678
Other metal-bearing materials in chief value of tungsten:				
China	—	—	15	227
Sweden	—	—	29	55
Total ¹	—	—	44	283
Chlorides of tungsten:				
Germany, Federal Republic of	—	—	(³)	5
Sodium tungstate:				
China	122	733	1,074	7,780
France	—	—	(³)	34
Germany, Federal Republic of	(³)	8	(³)	22
Hong Kong	73	476	192	1,130
Japan	(³)	5	(³)	19

¹ footnotes at end of table.

TABLE 15—Continued
U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1990		1991	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Korea, Republic of	—	—	24	209
Total¹	195	1,222	1,291	9,194
Tungsten carbide:				
Austria	(²)	\$1	1	\$11
Canada	22	256	19	335
China	26	484	50	826
Germany, Federal Republic of	519	8,987	154	2,652
Japan	3	125	2	96
Korea, Republic of	38	642	41	723
Luxembourg	24	1,031	33	1,340
Sweden	26	1,014	110	3,578
United Kingdom	23	360	9	232
Other	(³)	17	5	195
Total¹	681	12,917	423	9,988

¹Revised.

²Data may not add to totals shown because of independent rounding.

³Less than 1/2 unit.

⁴Estimated from reported gross weight.

Source: Bureau of the Census.

TABLE 16
U.S. IMPORT DUTIES ON TUNGSTEN

Item	HTS No.	Rate of duty effective Jan. 1, 1991	
		Most favored nation (MFN)	Non-MFN
Tungsten ores and concentrates	2611.00.0000	\$0.37 per kilogram on tungsten content	\$1.10 per kilogram on tungsten content.
Tungsten oxides	2825.90.3000	10% ad valorem	45.5% ad valorem.
Tungstic acid	2825.90.6010	3.7% ad valorem	25% ad valorem.
Chlorides of tungsten	2827.39.4000	10% ad valorem	45.5% ad valorem.
Ammonium tungstates	2841.80.0010	10% ad valorem	49.5% ad valorem.
Calcium tungstate	2841.80.0020	10% ad valorem	49.5% ad valorem.
Other tungstates	2841.80.0050	10% ad valorem	49.5% ad valorem.
Tungsten carbide	2849.90.3000	10.5% ad valorem	55.5% ad valorem.
Other tungsten compounds	2850.00.1000	10% ad valorem	45.5% ad valorem.
Mixtures of inorganic compounds, chief value tungsten	3823.90.3500	10% ad valorem	45.5% ad valorem.
Ferrotungsten and ferrosilicon tungsten	7202.80.0000	5.6% ad valorem	35% ad valorem.
Tungsten powders	8101.10.0000	10.5% ad valorem	58% ad valorem.
Tungsten waste and scrap	8101.91.1000	4.2% ad valorem	50% ad valorem.
Unwrought tungsten	8101.91.5000	6.6% ad valorem	60% ad valorem.
Wrought tungsten—bar, rod, sheet, etc.	8101.92.0000	6.5% ad valorem	60% ad valorem.
Wrought tungsten—wire	8101.93.0000	6.5% ad valorem	60% ad valorem.
Wrought tungsten—other	8101.99.0000	5.5% ad valorem	45% ad valorem.

TABLE 17
WORLD TUNGSTEN ANNUAL MINE PRODUCTION CAPACITY,
DECEMBER 31, 1991

(Metric tons of tungsten content)

	Rated capacity ¹
North America:	
Canada	3,000
Mexico	300
United States	3,700
Total	7,000
South America:	
Argentina	40
Bolivia	1,400
Brazil	500
Peru	1,600
Total	3,540
Europe:	
Austria	1,400
Czechoslovakia	50
Portugal	1,400
Spain	50
Sweden	350
U.S.S.R.	8,000
Total	11,250
South Africa, Republic of	
Rwanda	150
Uganda	10
Zaire	15
Total	175
Asia:	
Burma	300
China	25,000
India	20
Japan	300
Korea, North	1,000
Korea, Republic of	1,200
Malaysia	10
Mongolia	500
Thailand	500
Turkey	200
Total	29,030
Oceania:	
Australia	2,250
New Zealand	10
Total	2,260
World total	53,255

¹Includes capacity at operating mines as well as mines on standby basis.

TABLE 18
TUNGSTEN: WORLD CONCENTRATE PRODUCTION, BY COUNTRY¹

(Metric tons of tungsten content)

Country	1987	1988	1989	1990	1991 ²
Argentina	14	13	20	*16	15
Australia	1,150	1,616	1,371	*1,086	² 237
Austria	1,250	1,235	*1,517	*1,378	1,400
Bolivia	638	900	1,118	*1,014	² 1,060
Brazil	800	738	679	422	500
Burma	493	307	*300	*311	300
China ³	21,000	³ 30,000	³ 30,200	³ 32,000	25,000
Czechoslovakia ⁴	45	50	² 74	² 83	80
India	26	19	12	*13	10
Japan	259	266	296	*254	² 279
Korea, North ⁵	500	500	500	1,000	1,000
Korea, Republic of	2,375	2,029	1,701	*1,361	² 1,037
Mexico	213	206	170	*183	190
Mongolia ⁶	1,500	1,000	1,000	500	300
New Zealand ⁷	5	5	5	—	—
Peru	205	432	*970	*1,536	1,600
Portugal	1,207	1,382	1,381	1,405	1,400
Rwanda	11	*22	105	*156	175
Spain	81	80	*58	*49	50
Sweden	574	420	80	—	—
Thailand	705	651	603	*290	300
Turkey	163	125	*100	(²)	² —
Uganda ⁸	4	4	4	4	4
U.S.S.R. ⁹	9,200	9,200	9,300	8,800	8,000
United Kingdom	—	3	28	42	9
United States	34	W	W	W	W
Zaire	21	20	16	*14	13
Zimbabwe ¹⁰	1	1	1	1	1
Total	42,474	² 51,224	² 51,609	² 51,918	42,960

¹Estimated. ²Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

³Table includes data available through May 14, 1992.

⁴Reported figure.

⁵Revised to zero.

TABLE 19
TUNGSTEN: WORLD CONCENTRATE CONSUMPTION, BY COUNTRY¹

(Metric tons of tungsten content)

Country ²	1987	1988	1989	1990	1991 ³
Argentina	65	30	38	40	30
Australia ⁴	70	50	50	50	60
Austria ⁴	2,000	2,100	1,800	1,800	1,600
Belgium-Luxembourg	50	50	2	—	—
Brazil	867	753	688	400	400
Bulgaria ⁴	100	100	50	50	50
Canada	765	386	300	290	200
China ^{2 3}	9,000	14,000	14,000	12,000	12,000
Czechoslovakia ⁴	1,200	1,200	1,700	600	500
France	269	34	—	—	—
Germany, Federal Republic of:					
Eastern states	300	300	300	300	300
Western states	1,863	2,144	2,576	749	400
Hungary ⁴	400	500	500	200	200
India	250	187	200	200	200
Italy ⁴	86	20	—	—	—
Japan	2,119	1,980	1,538	1,440	1,400
Korea, North ²	500	1,000	1,000	1,500	1,500
Korea, Republic of	1,950	1,580	2,000	1,950	2,000
Mexico	64	9	5	5	—
Netherlands ⁴	300	330	350	200	200
Poland ⁴	744	424	—	—	—
Portugal	20	—	—	—	—
South Africa, Republic of	203	242	153	114	100
Spain ⁴	20	30	20	20	20
Sweden	567	324	320	380	200
U.S.S.R. ²	15,000	14,500	14,500	10,000	10,000
United Kingdom ⁴	100	50	50	50	20
United States	5,506	7,832	7,725	5,878	5,309
Total	44,378	50,155	49,865	38,216	36,689

¹Estimated. ²Revised.

³Source, unless otherwise specified, is Tungsten Statistics, UNCTAD Committee on Tungsten.

⁴Estimated by the U.S. Bureau of Mines.

⁵Combined internal consumption plus that which was processed to intermediate products and subsequently reported.

⁶Apparent consumption, production plus imports minus exports.

⁷Reported figure; excludes 2 months of "withheld" data.

FIGURE 1
QUANTITY OF TUNGSTEN CONCENTRATE SHIPPED
FROM MINES IN THE UNITED STATES

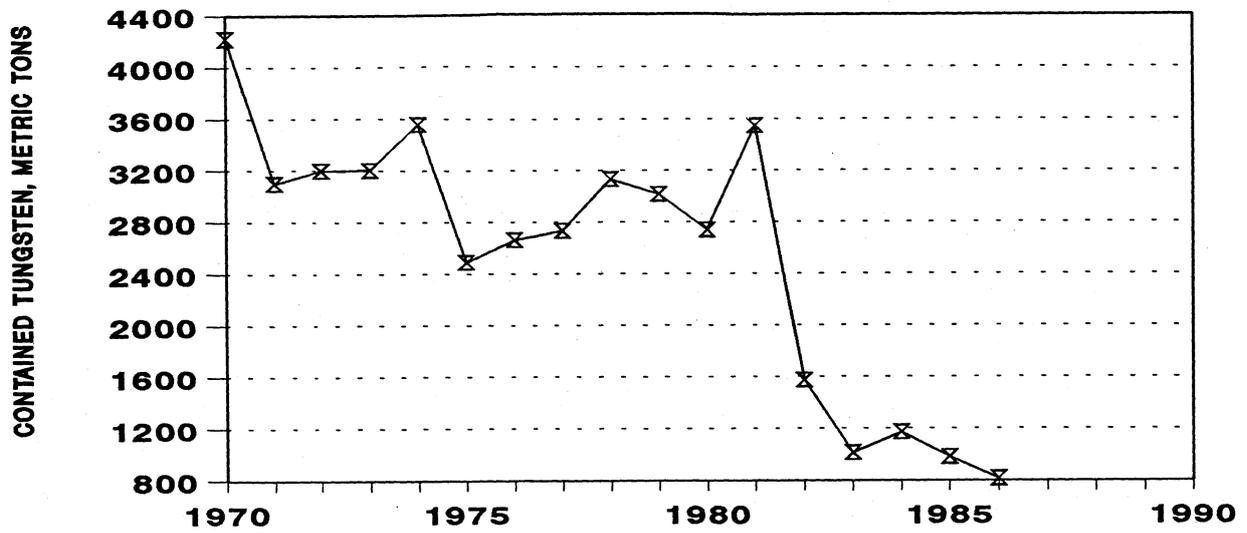
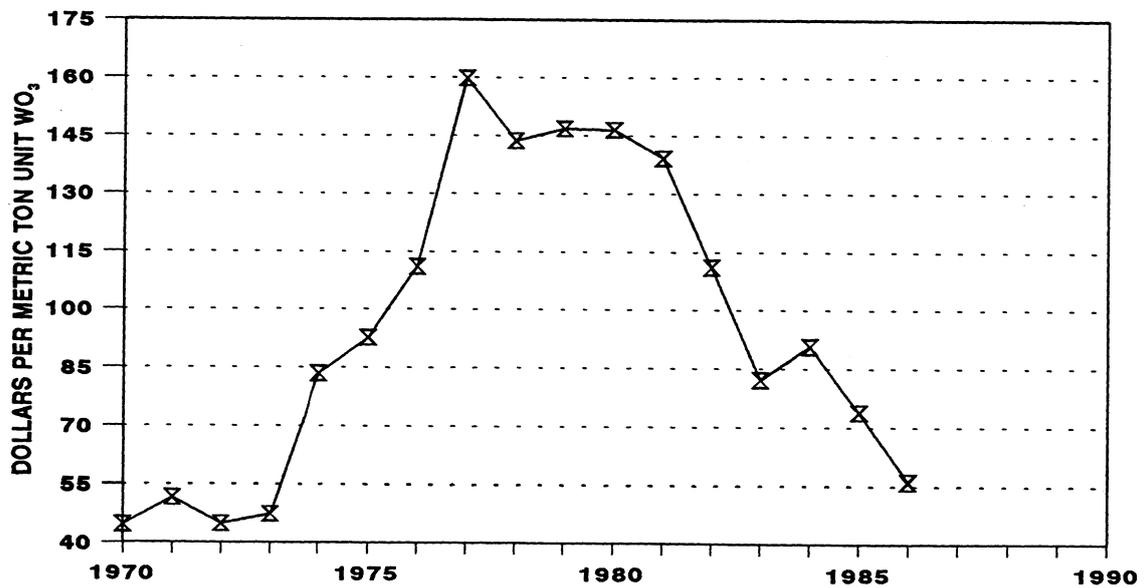


FIGURE 2
VALUE OF TUNGSTEN CONCENTRATE SHIPPED
FROM MINES IN THE UNITED STATES



VANADIUM

By Henry E. Hilliard

Mr. Hilliard, a physical scientist with more than 20 years' U.S. Bureau of Mines experience, has been the commodity specialist for vanadium since 1986. Domestic survey data were prepared by Lisa Harley, statistical assistant; and international data tables were prepared by Ronald L. Hatch, international data specialist.

The principal use of vanadium is as an alloying element in steel. The addition of small amounts of vanadium, often less than 1%, to an ordinary carbon steel can significantly increase its strength and improve both its toughness and ductility. Such high-strength low-alloy (HSLA) steels are attractive in the construction of highrise buildings, bridges, large-diameter pipelines, and automobiles because of the weight savings obtained. Vanadium-aluminum alloys of titanium are widely used in the aerospace industry. Oxides and chlorides of vanadium play important roles as catalysts in the production of sulfuric acid and other key organic chemicals.

The U.S. Bureau of Mines began reporting statistical data on vanadium in the metric system of units in the 1990 Annual Report. Throughout this report, data will be reported in kilograms (kg) and metric tons (tons) unless otherwise stated. The English system of units will no longer be used to report statistical data in official U.S. Bureau of Mines reports.

In 1991, steelmaking continued to account for more than 80% of domestic vanadium demand. Consumption declined for the third consecutive year from 4,100 metric tons in 1990 to 3,300 tons in 1991. Imports of vanadium raw materials decreased overall compared with those of 1990. Imports of ores, slag, and residues were the lowest since 1986. Exports also decreased sharply from the near record levels in 1989 and 1990.

The downward pressure on prices of vanadium that began in the later part of 1990 showed no sign of relenting in 1991 as demand in most end-use sectors,

especially specialty steels, continued to soften. In addition to the drop in demand brought about by the economic recession, new steel rolling technology, which can impart the same characteristics as were previously achieved by alloying steel with vanadium, had an adverse effect on demand. Columbium can be substituted for vanadium in many applications, and this is affecting vanadium requirements. The market also suffered from oversupply, with output exceeding demand by 2,268 tons or about 5 million pounds.

The pattern of vanadium use in the United States is not expected to change significantly in the near future, but the level of consumption will be subject to fluctuations in domestic and global steel production.

DOMESTIC DATA COVERAGE

Domestic consumption data for vanadium are developed by the U.S. Bureau of Mines from a voluntary survey of all known domestic consumers. In 1991, there were 83 responses to the consumption survey, representing 81% of the total canvassed. These 83 respondents are estimated to have accounted for 95% of total domestic consumption, or about 3,121 tons. The estimated consumption of nonrespondents, derived using their past consumption relationships, trends, and data from nonsurvey sources, was about 164 tons. The consumption quantity of 3,285 tons shown in table 1 is the U.S. Bureau of Mines' estimate of total U.S. (reported) vanadium consumption.

BACKGROUND

Definitions, Grades, and Specifications

The term ferrovanadium as used by the U.S. Bureau of Mines includes vanadium-carbon-iron-nitrogen proprietary alloys as well as the conventional forms of ferrovanadium. Some of the more common commercial products are listed in table 2. A standard specification for ferrovanadium has been developed by the American Society for Testing Materials (ASTM).¹

Aluminum-vanadium master alloys contain fixed ratios of vanadium to aluminum and are used in the manufacture of titanium alloys. Amounts of vanadium up to 1 weight-percent improve the strength of titanium-base alloys and promote their thermal stability in the presence of moderate amounts of aluminum. When amounts greater than 4 weight-percent are added, the titanium-base alloy can be significantly strengthened by heat treatment. The three most important commercial titanium alloys containing vanadium are Ti-6Al-4V, Ti-6Al-4V-2Sn, and Ti-8Al-1Mo-1V. The Ti-6Al-4V alloy presently accounts for more than 50% of the titanium-base alloy market.

Products for Trade and Industry

Vanadium is usually traded on the international market in the form of technical grade V_2O_5 and 50% to 80% FeV. Most world exports of vanadium

raw material are in the form of vanadium-bearing iron slag from China and the Republic of South Africa, while U.S. and Western European converters are the major importers of these materials. U.S. and Western European converters are the major exporters of downstream vanadium products such as vanadium oxides and FeV to the many small consuming countries. These converters also compete for the major markets for pentoxide and FeV exported to Japan and the Republic of Korea. Trade in ferrovanadium is dominated by the major European and U.S. converters. A large part of this trade is within Europe, but exports are also made to many other consuming countries, particularly by the Federal Republic of Germany.

Industry Structure

The vanadium industry has a five-tiered structure with facilities on six continents. As expected, mines and oilfields form the base of the structure (figure 1). Since 1979, an estimated 83% of world production has come from vanadiferous magnetite (Fe_3O_4). The principal sources of the magnetite ore were China, the Republic of South Africa, and the U.S.S.R. World vanadium production for 1987-91 is shown in table 17. The other 17% of the vanadium was recovered from other petroliferous materials and spent catalysts.

The second tier is a set of economically unrelated facilities that include (1) pig iron plants with slag recovery units, (2) elemental phosphorus smelters, and (3) generators of petroleum residues, fly ash, and spent catalysts that contain vanadium either as the active material or as a contaminant.

The third tier consists of (1) acid leaching plants with solvent extraction circuits and (2) salt roasting operations. Technical-grade V_2O_5 and NH_4VO_3 are the principal products at this level.

In order to have an easily marketable product, it is customary at this point to either convert the oxides into an alloy or upgrade their purity to greater than 98.5

weight-percent. The two traditional alloy products have been the 80 weight-percent ferrovanadium and 35 weight-percent aluminum-vanadium master alloy. Variations of five different reduction processes are currently in use throughout the world, with aluminum, carbon, or silicon serving as the reductant. These conversion and upgrading plants, which form the fourth tier of the structure, may be a considerable distance from the mills and slag plants and frequently blend feed materials to improve recovery.

Of the more than 30 privately owned vanadium companies, only 1, the Republic of South Africa's Highveld, operates facilities at all 4 lower levels and can be considered totally integrated. Highveld has plants that process vanadiferous magnetite ores from the Bushveld Igneous Complex. Two other producers, Shieldalloy Metallurgical Corp. and Stratcor, have extensive operations on the second, third, and fourth tiers. Shieldalloy traditionally used Highveld slag as its starting material for low vanadium grades of ferrovanadium.

The fifth tier is composed of producers of vanadium specialty alloys, high-purity vanadium metal, primary vanadium chemicals, and vanadium catalysts. Reading Alloys Inc., Akzo Chemical, and Teledyne Wah Chang Albany illustrate the diversity of operations at this level.

The Republic of South Africa is the world's largest producer of ore and vanadium-bearing slag. Its annual production of more than 17,000 tons is approached only by production in the U.S.S.R. The bulk of Soviet production is consumed internally or by other Eastern European countries. Other major producers include China and the United States. Canada, Japan, and Western Europe are heavily dependent on imports of vanadium slag and pentoxide from the Republic of South Africa. Any disruption of South African supplies could seriously upset the balance between vanadium supply and demand.

Geology-Resources

Vanadium is found in many parts of the world, usually in association with other minerals. There are few ores from which vanadium can be economically extracted as a single product. It is, therefore, often extracted as a byproduct or coproduct in the production of other elements, such as iron, phosphorus, or uranium. Increasing amounts are being recovered from petroleum residues and spent catalysts. The world also has extensive subeconomic resources of vanadium contained in oil sands, carbonaceous shale, and bauxite.

The crustal abundance of vanadium is estimated to be 100 to 150 parts per million (ppm), about twice that of copper, 10 times that of lead, and almost 100 times that of molybdenum.² As a result, trace vanadium mineralization occurs in a wide range of geologic provinces and environments. At the same time, ore deposits of vanadium are rare because much of the vanadium in igneous rocks occurs dispersed in the relatively insoluble trivalent state and is substituting for ferric iron in ferromagnesian silicates, magnetite, ilmenite, and chromite. Because of the substitutional phenomenon at the atomic level, vanadium is more abundant in mafic (those high in magnesium and iron) than silicic rocks. Gabbros and norites typically contain 200 to 300 ppm vanadium compared with 5 to 80 ppm for granites. When mafic rocks weather in a humid climate, the vanadium remains in the trivalent state or is weakly oxidized to the relatively insoluble tetravalent state. In either case, the vanadium is captured along with aluminum in the residual clays. Subsequent leaching of the clays can produce bauxite and lateritic iron ores that contain 400 to 500 ppm vanadium. When mafic rocks are intensely oxidized in an arid climate, some of the vanadium is converted to the pentavalent state. The pentavalent cation is considerably more soluble than the trivalent cation, is readily dissolved by ground water, and can be transported over long distances. This transport phenomenon can be observed in arid parts of Western Australia where carnotite precipitates from ground water in calcreted drainage systems.³ At

Yeelirrie, for example, thin films of carnotite were formed in the voids and cavities of river fill when ground water percolated through a tertiary river channel.

Organic materials frequently play a key role in the depositional process by helping to create a reducing environment. At many locations on the Colorado Plateau, carnotite, tyuyamunite, and other secondary uranium-vanadium minerals replace fossil logs and other carbonized plant debris. Some of the best examples of this phenomenon can be seen in the Monument Valley and White Canyon districts where uranium-vanadium ores have been deposited in paleochannels of the Shinarump Member of the Upper Triassic Chinle Formation. Fossils in the Shinarump indicate that the stream channels were cut into the underlying Moenkopi mudstones and then filled with sands, pebbles, and plant debris before the end of the Triassic Period 195 million years ago. Although the uranium-vanadium ores are associated with plant remains, the two elements were precipitated from aqueous solutions percolating through the stream channels long after the host sandstones and conglomerates had formed. The genesis and age of the mineralization remain controversial.

The role of vanadium during the formation of fossil fuels is obscure. There appears to be a relationship between the relatively high concentration of vanadium in coal and petroleum and the burial and subsequent degradation processes that apparently formed the fuels from organisms. The structures of the vanadyl porphyrins found in crude oil are approximately identical to the structures of chlorophyll (magnesium-centered porphyrins present in green plants) and hemoglobin (iron-centered porphyrins present in the red corpuscles of blood). The ratio of vanadium to nickel in crude oil is a function of the oxidation-reduction potential (Eh), the hydrogen ion activity (pH), and sulfide activity of the environment in which the oil source rocks were deposited. The two metals both form stable metallo-organic complexes in the high molecular weight fractions of

crude oil.⁴ Cleavage of these vanadium and nickel bonds will not occur unless the crude oil is subjected to a temperature greater than 300° C. As a result, the vanadium-to-nickel ratio remains constant for a specific reservoir even when the lower molecular weight components migrate away. The ratio is therefore useful in identifying unmetamorphosed crude oil from different depositional facies of the same source rock.

Technology

Mining.—In the United States, vanadium is recovered as a principal mine product, as a coproduct from carnotite ores, and from ferrophosphorus slag as a byproduct in the production of elemental phosphorus. Increasingly, it is also being recovered from petroleum refinery residues, fly ash, and spent catalysts. In China and the Republic of South Africa, vanadium is recovered as a byproduct of pig iron production from titaniferous magnetite.

Processing.—The steel industry accounts for more than 80% of the world's consumption of vanadium as an additive to steel. It is added to the steelmaking process as a ferrovanadium alloy, which is produced commercially by the reduction of vanadium pentoxide or vanadium-bearing slag with aluminum, carbon, or ferrosilicon.

The first stage in the processing of vanadium-bearing ore is the production of an oxide concentrate. The ore is crushed, ground, screened, and mixed with a sodium salt. This mixture is roasted at about 850° C to convert the oxides to water soluble sodium metavanadate. The vanadium is extracted by leaching with water and precipitated at pH 3 as sodium hexavanadate (red cake) by the addition of sulfuric acid. The red cake is fused at 700° C to yield a dense, black product that is sold as technical-grade vanadium pentoxide. Technical-grade vanadium pentoxide contains a minimum of 86 weight-percent pentoxide and a maximum 8 weight-percent sodium oxide. The red cake may be further

purified by dissolving it in an aqueous solution of sodium carbonate. Aluminum, iron, and silicate impurities precipitate from solution upon pH adjustment. Ammonium metavanadate is then precipitated by the addition of ammonium chloride. The precipitate is calcined to give a vanadium pentoxide product of greater than 99.8% purity.

Vanadium is extracted as a coproduct with uranium from carnotite by direct leaching of the ore with sulfuric acid. An alternative method is roasting the ore followed by countercurrent leaching with dilute sulfuric acid. In some cases, the first leach may be with a sodium carbonate solution. The uranium and vanadium are then separated from the pregnant liquor by liquid-liquid extraction techniques.

More recently spent catalysts have become a major source of vanadium. The catalyst may be either oxidation catalyst used in the production of sulfuric acid and maleic anhydride or fluid cracking catalyst used in refining petroleum. Vanadium is recovered by first roasting the material in a controlled atmosphere in order to solubilize the vanadium and other trace metals; e.g., molybdenum and nickel. It is then milled, leached, and filtered to enable the separation of solids from the solution containing vanadium. The solutions go through various precipitation steps prior to the precipitation of vanadium as ammonium metavanadate, which is then decomposed and fused to form V₂O₅ or used directly to make other vanadium chemicals.

In China and the Republic of South Africa, vanadium is concentrated in slag resulting from the production of pig iron from magnetite ore. The ore, containing 1.5% to 2.5% vanadium pentoxide, is partially reduced with coal in rotary kilns. The ore is then melted in an enclosed furnace that produces a slag containing most of the titanium and pig iron containing most of the vanadium. After the titanium-bearing slag is removed, the molten pig iron is blown with oxygen to form a slag containing 12 to 24 weight-percent vanadium pentoxide. The slag is separated from the molten

metal and may then be used as a high-grade vanadium raw material in the usual roast-leach process.

In the aluminothermic process for preparing ferrovanadium, a mixture of technical-grade pentoxide, aluminum, iron scrap, and a flux are charged into an electric furnace, and the reaction between aluminum and pentoxide is initiated. The reaction is highly exothermic, producing very high temperatures. The temperature can be controlled by adjusting the particle size of the reactants and the feed rate of the charge and by using partially reduced pentoxide or by replacing some of the aluminum by a milder reductant. Ferrovanadium containing up to 80 weight-percent vanadium can be produced by this method.

Ferrovanadium can also be prepared by the thermit reaction, in which vanadium and iron oxides are coreduced by aluminum granules in a magnesia-lined steel vessel or in a water-cooled crucible. The reaction is initiated by a barium peroxide-aluminum ignition charge. This method is also used to prepare vanadium-aluminum master alloys for the titanium industry.

The production of ferrovanadium by the reduction of vanadium concentrates with silicon involves a two-stage process in which technical-grade vanadium pentoxide, ferrosilicon, lime, and fluorspar are heated in an electric furnace. An iron alloy containing about 30% vanadium but undesirable amounts of silicon is produced. The silicon content of the alloy can be reduced by adding more pentoxide and lime to effect the extraction of most of the silicon into the slag phase. An alternative process involves the formation of a vanadium-silicon alloy by the reaction of vanadium pentoxide, silica, and coke in the presence of a flux in an arc furnace. The molten metal reacts with vanadium pentoxide yielding ferrovanadium. The silicon reduction method has not been used extensively.

A process developed by Foot Mineral Co., Cambridge, OH (now Shieldalloy Metallurgical Corp.), has been used to produce tonnage quantities of ferrovanadium. This process involves the

reaction of vanadium-bearing iron slag with silica, flux, and a carbon reductant followed by refinement by vanadium pentoxide. The reaction takes place in a submerged electric arc furnace yielding a ferrovanadium alloy containing about 40 weight-percent vanadium, 3.5 weight-percent silicon, 3.8 weight-percent manganese, 0.1 weight-percent carbon, and the remainder iron.

Substitutes

Various metals, such as columbium, manganese, molybdenum, titanium, and tungsten, are, to some degree, interchangeable with vanadium. So far there are no substitutes for vanadium in the all-important aerospace titanium alloys, which were used in jet engine mountings and wing structures. High-purity vanadium compounds were used as catalysts in the production of sulfuric acid, maleic anhydride, and in pollution control technology where it was required to remove hydrogen sulfide gas from flu gases (Stretford Process). In only a few chemical applications could platinum and nickel replace vanadium catalyst.

Economic Factors

Prices.—Highveld Steel & Vanadium Corp. of the Republic of South Africa produced more than 60% of market economy countries' vanadium in 1991. Even though the bulk of Highveld's production was in the form of vanadium-bearing iron slag, its pentoxide price was seen as the benchmark worldwide, with other suppliers indexing some of their contracts on the price. South African producers, who set their prices quarterly, were charging \$2.95 per pound for V_2O_5 in first quarter 1991. By the fourth quarter, the price had fallen to \$2.60 per pound; spot, or free market, prices were even lower at about \$2.35 per pound. Highveld's prices were down from \$7.50 per pound in second quarter 1989 and \$5.00 in first quarter 1990. In Europe, the price of FeV hovered around the \$11.00 per kilogram vanadium content level for most of the year. The failure of the prices to advance as expected was

attributed to the continuing depressed demand for steel in Europe and the United States. Slack demand in the FeV market was balanced by reduced output from European converters and also by the fall in free market supplies of South African V_2O_5 . The poor performance of vanadium prices over this period reflected an oversupplied market and low demand as major consumers reduced their usage of vanadium.

Tariffs.—U.S. import duties on selected vanadium items as of January 1, 1991, are listed in table 3. The tariff listing includes rates for both most-favored-nation (MFN) and non-MFN status.

Operating Factors

Environmental Requirements.—Because some segments of the geochemical cycle of uranium and thorium coincide with the vanadium cycle, the environmental considerations of vanadium mining are frequently linked to the management of radioactive mine wastes. In addition to careful placement and containment of tailings ponds, special attention must be given to preventing or limiting radioactive contamination of ground water aquifers and to the impoundment and long-term storage of mill tailings and mine waste to control radon daughter exhalation.

In 1982, the Environmental Protection Agency (EPA) published a regulation dealing specifically with the mining of both vanadium ores and uranium-radium-vanadium ores.⁵ Under these rules, the concentration of uranium in mine drainage must be less than 4 milligrams per liter per day for 30 consecutive days. In addition, the U.S. Nuclear Regulatory Commission has issued two regulatory guides dealing with personnel monitoring at uranium mills and processing facilities. The two guides delineate techniques for performing a bioassay on workers routinely exposed to airborne yellowcake (U_3O_8) or airborne uranium ore dust.⁶

In October 1983, EPA published rules dealing with the stabilization and long-term control of mill tailings at inactive

uranium-vanadium processing sites.⁷ These rules, which took effect on December 6, 1983, required uranium-vanadium mill operators to install plastic liners or other protective barriers under their tailings piles to prevent uranium, its radioactive daughter products, and nonradioactive toxic substances such as selenium from contaminating ground waters. Each tailings pond was required to have an earthen cover to minimize emissions and prevent erosion of the sandy surface by wind and rain. The rules also limited radon release from the surface of the pile to 20 picocuries per square meter per second.

Toxicity.—Vanadium compounds are irritants chiefly to the conjunctiva and respiratory tract. Prolonged exposure may lead to respiratory irritations with mucus discharge and lower respiratory tract irritation with bronchitis and chest pains.⁸ Other noted effects of vanadium and its compounds have included contact dermatitis, conjunctivitis, and discoloration of the tongue. Vanadium in high concentrations may alter metabolic processes in animals and humans. The reported toxic effects of exposure to vanadium compounds have been acute, never chronic. Toxic effects vary with the compound involved; e.g., vanadium oxytrichloride (VOCl_3) liberates hydrogen chloride gas, and the oral lethal dose (LD_{50}) for V_2O_5 dust in rats is 23 milligrams per kilograms of body weight.⁹ The lethal dose value is used to express the toxicity of many compounds and is determined by experiment. As used here, it is milligrams of V_2O_5 per kilogram of body weight (taken by mouth) that is lethal to 50% of the experimental animals.

Vanadium metal and its alloys pose no particular health or safety hazard, but they do react violently with certain materials, including bromine trifluoride (BrF_3), chlorine, and some strong acids. The toxicity of vanadium alloys depends upon other components in the alloy.

The adopted threshold limit values for time weighted averages for airborne vanadium, including oxide and metal dusts of vanadium, is 0.5 milligrams per

cubic meter; the value for fumes of vanadium compounds is 0.05 milligrams per cubic meter. These limits are for normal 8-hour workday and 40-hour workweek exposures. The short-term exposure limit is 1.5 milligrams per cubic meter for dust.¹⁰ The ammonium salts of vanadic acid and vanadium pentoxide have been listed as toxic constituents in solid wastes under the Resource Conservation and Recovery Act.¹¹

ANNUAL REVIEW

Legislation and Government Programs

In July, Department of Defense officials issued a report calling for cutting the National Defense Stockpile (NDS) in half. The report revealed that, over time, the Department would like to reduce the stockpile to \$5.6 billion from the current \$9.1 billion. If the Department of Defense plan had been approved by Congress, a number of commodities, including vanadium, would have been removed from the stockpile goal and would become excess material. In fiscal 1991, any stockpile disposal or acquisition had to be authorized by Congress. This new proposal would have given the Defense Logistics Agency (DLA) authority to set stockpile requirements, and thus buy and sell materials, without prior congressional approval. Department of Defense officials maintained that its new goals continue to meet the requirements for a 3-year conventional war, based on current data. The plan would have taken place at the end of September. The U.S. mining industry and foreign governments dependent on mineral revenues opposed any attempts to dispose of commodities even though DLA maintained its sales would not significantly disrupt the market. Likewise, many of the acquisitions faced opposition from special interest groups who would like to use the money elsewhere. The Department of Defense based its recommendations on the fact that major realignments in the perceived threat of war with the U.S.S.R. and short-term stabilization of problems in mineral-rich Republic of South Africa

created a new war scenario and revised structure for stockpile materials. As a result of the changed threat, the current inventory of materials, valued at about \$9.1 billion, could be safely reduced to about \$5.6 billion, according to the Department of Defense. However, final legislation adopted by House and Senate conference negotiations in November mandated that defense stockpile disposals and acquisitions for fiscal 1992 continue to be limited and monitored by Congress. Disposals must still be balanced equally by acquisitions and upgrades, but at a level that is 20% lower than that in 1990.

In December 1990, the Government of Argentina petitioned for duty-free treatment for ferrovanadium (HTS subheading 7202.92.00) under the General Systems of Preferences (GSP). In its request, Argentina stated that (1) this product has not been exported to the United States; (2) duty-free treatment of this product was accorded to certain other countries under the Caribbean Basin Economic Recovery Act and the United States-Israel Free-Trade Agreement; (3) the U.S. steel industry would benefit from a lower priced product; and (4) duty-free treatment would more than double the current Argentinean production level, thereby increasing (Argentinean) employment. The list of materials accorded GSP status is revised annually.

Opposing Argentina, Affiliated Metals and Minerals Inc. argued that (1) duty-free treatment would likely drive one of the few domestic producers out of the market by adding another competitor to a small-size market, and (2) duty-free imports of FeV would increase the level of unused industry capacity and cause unemployment in this labor-intensive industry. Shieldalloy and U.S. Vanadium also opposed the petition, noting that FeV has been treated by the U.S. Government as a "strategic and critical" mineral in the NDS. According to these producers, extending duty-free treatment would only serve to further decrease domestic FeV production and increase U.S. dependency on foreign sources. The petition was denied by the U.S. Trade representative in February.

Strategic Considerations

Vanadium is classified as a strategic and critical material because of the significant import dependence of the United States for its vanadium supply and because of the essential use of vanadium in equipment for defense, energy, and transportation.

Steel producers in the market economy countries (MEC) of the United States, Japan, and Western Europe shared a common concern about lack of economically viable domestic vanadium raw materials. Also, MEC vanadium supply was from only a few sources, chiefly China and the Republic of South Africa and from just three or four suppliers in these countries. China was expected to soon become a net importer of vanadium, leaving only South Africa and perhaps the Commonwealth of Independent States as the only major sources. Japan and Western Europe are more heavily dependent on imports than the United States.

The status of goals and inventories of vanadium materials in the NDS at the end of 1991 is given in table 4. No changes in goals were made. However, U.S. Vanadium Corp., Hot Springs, AR, completed the upgrade of 1.93 million pounds of stockpiled V_2O_5 to Grade B fused flake.

Issues

Prior to about 1984-85, more than one-half of the vanadium mined in the United States was recovered as a coproduct with uranium from sandstone mined on the Colorado Plateau. Companies recovering vanadium from uranium ores were hurt by the downturn in nuclear powerplant construction in the aftermath of the Three Mile Island nuclear reactor accident and the subsequent reduced demand for enriched uranium. Worldwide recession, high interest rates, and the cancellation of powerplant construction in the United States caused the Nuclear Exchange Corp. (Nuexco) exchange value of uranium oxide (U_3O_8) to decline from \$40.75 per pound in early 1980 to less than \$10.00 per pound in 1991. The

exchange value is Nuexco's judgment of the price at which transactions for significant quantities of uranium concentrates could be concluded on a specified date. Value is based on bids to buy and offers to sell, as well as recently completed and pending transactions.

A direct result of the price decrease was mill closing and decommissioning, personnel cutbacks, and canceled development and expansion plans. This unstable situation had the potential for creating a much higher degree of dependence by the United States on South African and Chinese imports. However, some of the slack was taken up by increased recovery of vanadium from petroleum residues, including spent petroleum catalysts. Recovery of vanadium from this source began during the 1973 and 1978 Arab oil embargoes. After being cut off from light crude from the Middle East, refiners were forced to process crude oils with high-sulfur and high-metal content. The trend toward heavier, sour crude and a tightening of sulfur restrictions on fuel products led to the development of the "Flexicoking" process, which concentrated 99% of the metals in the feed in a 2% solid purge from the system. This material has become an important source of vanadium, and in some instances, molybdenum and nickel. At the same time, the combustion of increasingly metalliferous fuel oils at powerplants created a second source of feed materials in the form of fly ash and boiler scale. More V_2O_5 produced in the United States is now being recovered from refinery residues, fly ash, boiler scale, and spent catalysts than ever before. In 1991, the United States recovered 2,250 tons of vanadium oxides from these petroliferous materials, most of which were imported. While this is essentially unchanged from that of 1990, production from residues and spent catalysts as a percentage of reported consumption increased from 56% to 69% in 1991.

Production

Vanadium is often considered to be an uncommon element, but actually its

abundance in the Earth's crust is comparable to or greater than that of copper, nickel, and zinc. Although there is a plentiful supply of vanadium, it is one of the most expensive elements to recover. In most cases, whether vanadium occurs as a primary ore, a coproduct, or in petroleum, the vanadium content of the material usually runs 1.5% V_2O_5 or less. V_2O_5 is the principal starting material for the production of all vanadium compounds. Therefore, when one speaks of vanadium production or the supply side of the industry, only those involved in the production of V_2O_5 should be included.

At yearend, there were five companies producing V_2O_5 in the United States. Of these, one was a totally integrated company that produced V_2O_5 , vanadium chemicals, FeV, and other vanadium alloys. The others produced mainly V_2O_5 from a variety of raw materials.

Consumption, Uses, and Stocks

Vanadium has been used as an alloying element in steel since 1902, when it was first added to tool steels used for high-speed machining operations. It was found that vanadium prevented grain growth in tungsten-bearing steels and enabled the steels to maintain their hardness at the high temperatures generated in tool steels during high-speed machining. Vanadium is also widely used in high-temperature steels used in steam powerplants. Chromium-vanadium steels are used for steel pipes and headers, and molybdenum-vanadium steels are used for rotors because of the high creep resistance produced by vanadium carbides.

Metallurgical applications accounted for more than 95% of vanadium consumption, with about 83% for steelmaking. Relatively small quantities of vanadium were used for alloying with nonferrous metals, mostly aluminum. Nonmetallurgical applications included catalysts, ceramics, and vanadium chemicals. The dominant nonmetallurgical use was in catalyst. Much less was consumed in ceramic and electronics (batteries).

Reported consumers' and producers' stocks of vanadium oxides, metal, alloys, and chemicals at yearend totaled 935 tons of contained vanadium; at yearend 1990, the number was 1,082 tons.

Foreign Trade

Overall U.S. exports of vanadium products were down by more than 50% in 1991. In decreasing order, Canada, Belgium-Luxembourg, Brazil, Japan, and Mexico were the leading importers of U.S. materials. Most countries imported almost exclusively V_2O_5 . Canada, the Republic of Korea, and Venezuela also imported substantial quantities of FeV. Exports of V_2O_5 totaled 700 tons gross weight, less than one-third of 1990 exports. Exports of FeV totaled 178 tons gross weight, down from 334 tons in 1990.

Imports for consumption of downstream vanadium compounds increased slightly in 1991; imports of raw materials, slag, ash, etc., were down sharply. FeV imports totaled 524 tons gross weight, up from 305 tons in 1990. The imported FeV averaged 81% vanadium, with a mean custom value of \$12.79 per kilogram of contained vanadium, down from \$13.57 in 1990. Canada was the leading source of FeV, with shipments of 131 tons, followed by Austria, 109 tons, and Belgium, 71 tons. Vanadium pentoxide imports totaled 133 tons of contained vanadium, up from 83 tons in 1990; the average declared value was \$3.22 per pound of contained vanadium, down from \$5.15 in 1990. Imports for consumption of vanadium-bearing slag totaled only about 178 tons of contained vanadium, all from the Republic of South Africa. An assortment of petroleum residues, spent catalyst, and fly ash totaling about 1,300 tons of V_2O_5 was imported from a variety of countries.

World Review

Industry Structure.—Vanadium was traded on the world market in vanadium-bearing slag, petroleum residues, technical-grade V_2O_5 , and FeV. The

Republic of South Africa was the largest producer with more than 60% of the MEC market. Most of the Republic of South Africa's exports of vanadium were in the form of vanadium-bearing iron slag. Japan and Western Europe were the chief importers of this material. The United States imported slag from the Republic of South Africa, and fly ash, petroleum residues, and spent catalyst from many other sources. The large importers of vanadium raw materials, e.g., slag, were the chief exporters of V_2O_5 , FeV, and other downstream vanadium products. This trade was dominated by a few large West European converters who competed not only within Europe, but also exported to many large and small consumers outside of Europe. Reliable statistics from the U.S.S.R. were not available, but it is believed to be second only to the Republic of South Africa in vanadium production. All Soviet trade was thought to be with other East European countries.

Capacity.—The data in table 15 are rated capacity for mills producing vanadium oxides as of December 31, 1991. Included in this data is capacity to produce vanadium-bearing slag and petroleum coke. Rated capacity is defined as the maximum quantity of product that can be produced on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgement of the author, can be brought back into production within a short period with minimum capital expenditure.

Australia.—Western Australia has large deposits of magnetite ores containing vanadium and titanium. The deposits consist of a large magnetite-rich intrusive rock. A chemical analysis of the material, undertaken more than 20 years ago, found about 0.32% V_2O_5 . This deposit was ignored for many years because of the low price of vanadium.

As the price of vanadium climbed from 1987 through 1989, Precious Metals Australia (PMA) reevaluated the deposit at its wholly owned Wagoo Hills Project in the Murchison District of Western Australia. This time, the titanium and vanadium mineralization was found to grade up to 0.93% V_2O_5 and 12% titanium dioxide (TiO_2). The deposit lies within a distinct and reasonably well-defined geologic structure known as Shepard's Discordant Zone (SDZ), which extends along a 10-mile strike within PMA's property. The latest sampling was carried out across the SDZ in areas of abundant titanomagnetite surface rock with samples collected at 2- and 6-yard intervals. Analysis of the samples indicated that the region was likely to contain up to 40 million tons of high-iron magnetite ore containing an average of 0.75% V_2O_5 and as much as 12% titanium.¹²

Preliminary metallurgical work suggested that a magnetite concentrate could be produced from grinding and magnetic separation. A \$70 million mine development and processing plant was planned to produce about 2,100 tons of V_2O_5 per year. PMA was determined to continue the development of this project despite low vanadium prices in 1990 and even lower prices in 1991. PMA officials believed Australian mining and materials handling technology to be more efficient than methods used in the Republic of South Africa. They also believed that the Australian ore would be easier to process. PMA has the disadvantage of higher energy costs.

Canada.—Agra Industries Ltd. of Saskatoon, Saskatchewan, teamed with Renzy Mines Ltd. and Fairfax Financial Holdings Ltd. of Toronto, Ontario, to construct a vanadium pentoxide facility at Fort McMurry, Alberta. The plant, which cost about \$14 million, was designed to extract about 2.5 million pounds per year of V_2O_5 from waste fly ash produced by the Suncor Inc. oil sands plant.¹³

Carbovan began production of vanadic acid (HVO_3) in September 1990 and shipped the material to consumers in

Canada and the United States. After less than a year of operation, Carbovan suspended operations indefinitely. Twenty-eight workers were laid off, and equipment was mothballed in May. The stoppage was attributed to the depressed market for vanadium that eroded revenues to the point where the plant was no longer economically viable. Agra Industries, the primary shareholder in the project, noted that free market V_2O_5 was selling for only \$2.50 per pound in May, well below Carbovan's cost of production. In addition to low V_2O_5 prices, high interest rates and the high value of the Canadian dollar were also named as reasons for the closure.

South Africa, Republic of.—Total vanadium production, estimated at about 24,000 tons as V_2O_5 , declined for the second consecutive year. Production in 1990 was reported to be 30,535 tons.¹⁴

After about 2 years in the market, Union Steel Co. (Usko) quit the vanadium business and sold its vanadium assets to Rhombus Vanadium (Rhovan) for the nominal sum of R1.0. Soon after the sale Rhovan announced that its vanadium mine and the Usko plant would be closed indefinitely. Under terms of the sale agreement, Usko, which invested about R60 million in its vanadium plant, paid Rhovan R19 million in cash for what was described as damages for cancellation of Rhovan's 20-year contract to supply Usko with 250,000 tons per year of magnetite. The payment was to be made by March 31, 1992, and included interest. Rhovan officials did not rule out the possibility of reopening the mine and plant at some later date, stressing that it possessed large, high-quality reserves, and now a plant to process them into V_2O_5 . The plant had a theoretical capacity of 19.8 million pounds V_2O_5 per year. The plant, which was commissioned in September 1990, began production at the intermediate rate of 3.6 million pounds per year and eventually reached 6 million, far short of its design capacity. Continuous technical problems and the low price of V_2O_5 caused Usko to suffer large losses and the eventual sale of its vanadium operations. Meanwhile,

Vanadium Technologies (Vantec), formerly the vanadium interest of Vansa Vanadium, expected to complete modification of its V_2O_5 plant in early March 1992. The modifications were designed to improve operating efficiency. Coincidentally, they will also increase V_2O_5 capacity by about 33%. Production from the plant was expected to reach the market in the second quarter of 1992.

Vansa's vanadium operations had been idle since November 1990 when the company took the view that the vanadium market was severely depressed and no improvement could be seen in the short- or medium-term. Vantec gambled that despite current market conditions, the plant could be a viable operation in the long-term.

Highveld Steel & Vanadium Corp., the world's largest vanadium producer, announced in August that it plans to locally convert a portion of its vanadium-bearing slag output into V_2O_5 . The company will spend R10 million at its Vantra division (closed since August 1991) to enable up to 20% of its slag output to be converted to V_2O_5 . Highveld assured its slag customers in Europe, Japan, and the United States that the move would not affect its commitment to supply them with slag.

Other established producers in the Republic of South Africa apart from Highveld are Vametco in Bophuthatswana and Transvaal Alloys, which produced V_2O_5 and other vanadium chemicals. The Republic of South Africa's domestic consumption of vanadium was believed to be about 1% of its total production.

OUTLOOK

An economic recession held various world economies and the world vanadium industry in check during 1991. A number of signs point to impending recovery. However, the end of any economic slowdown would take time to affect the vanadium industry. If the turnaround were to begin in early 1992, it would be late in the year before the vanadium industry would see a return to profit and growth.

Some realignment and restructuring of the industry took place in 1991, with the shutdown of plants, acquisitions and divestiture of businesses, and idling of plant capacity—a trend likely to continue throughout 1992. In short, 1992 promises to be a year of rebuilding for the vanadium industry. It will be a year for rebuilding markets and thus sales, earnings, and profitability.

Any upturn in the economy will help the vanadium industry, but it is not likely to see the growth rate prevalent in the late 1980's, and the vanadium industry will probably lag the general economy in turning around. Working against rapid turnaround are a number of factors, including low demand for vanadium in still weak, major end-use markets. Chief among these is the steel industry (construction and automobiles). Commercial construction is very weak and will continue to be so for some time as vacancy rates in office buildings remain high across the country. There are some hopeful signs in the residential market. The auto industry, on the other hand, seems unable to fully rebound. Throughout the year, sales of domestically produced automobiles were weak, down 20% from the same period in 1990. The constraints on demand have had a number of deleterious effects on the vanadium industry, including lower capacity utilization and prices. Some vanadium capacity, the Precious Metals Australia project for example, still was expected to come on-stream in the near future, thus almost guaranteeing that capacity use is not going to rebound as the industry would like.

World demand is forecast to increase by an average of 2% per year, with total world demand reaching 45,000 tons by the year 2000. World production in 1991 was estimated to have been more than 30,000 tons, including about 2,300 tons produced in the United States from petroleum residues and spent catalysts. U.S. production from domestic ores and concentrates was not reported.

Long-term prospects for this highly cyclical industry depend on a number of factors. Producers will certainly be adversely affected by any future

economic downturn. Because of restructuring and downsizing that occurred in the industry during the last recession, the industry will be better able to cope with a recession than it was in the early 1980's. Traditional forces, such as the demand for motor vehicles and machinery, the level of economic activity, and the use of substitute materials, will continue to be of central importance. The strength of the U.S. dollar and its trade effects will also influence the industry's long-term future.

More than 95% of the demand for vanadium is driven by steel and nonferrous metallurgical applications. This dependence of the vanadium industry on the demand for steel products is not likely to change in the near future. The remaining demand is driven by chemicals applications. The reader is referred to the outlook section of the Iron and Steel Annual Report for more information on the long-term outlook for the steel industry.

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¹⁴Briefing Paper. Vanadium Pentoxide Plant Fort McMurry, Alberta. Carbovan Inc., 2200 Mississauga, Ontario, Canada.

¹⁵Mining Journal. Chinese Vanadium Output. V. 313, No. 8047, Nov. 24, 1989, p. 424.

¹⁶South Africa's Mineral Industry 1989. Department of Minerals and Energy Affairs, Minerals Bureau, Republic of South Africa, p. 136.

¹⁷The TEX Report. V. 21, No. 4892, Apr. 11, 1989, p. 3.

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Roskill Reports (London).

TABLE 1
SALIENT VANADIUM STATISTICS

(Metric tons of contained vanadium unless otherwise specified)

	1987	1988	1989	1990	1991
United States:					
Production:					
Ore and concentrate:					
Recoverable vanadium ¹	W	W	W	W	W
Value	thousands	W	W	W	W
Vanadium oxide recovered from ore ²	W	W	W	W	W
Vanadium recovered from petroleum residue ³	2,275	2,950	2,389	2,3080	2,250
Consumption	4,221	4,834	4,646	4,081.16	3,285
Exports:					
Ferrovanadium (gross weight)	396	571	493	334	178
Oxides and hydroxides ⁴	—	—	1,080	976	1,100
Vanadium pentoxide (anhydride)	743	620	¹ 1,171	819	392
Other compounds (gross weight)	435	887	⁶ 888	1,472	816
Imports (general):					
Ferrovanadium (gross weight)	383	134	650	323	428
Oxides and hydroxides	—	—	106.27	270.93	49.94
Ore, slag, ash, and residues	2,054	3,616	⁴ 2,210	3,826	882
Vanadium pentoxide, anhydride	324	382	133	83	145
World: Production from ore, concentrate, slag ⁵	³ 30,042	³ 31,731	³ 32,667	30,606	² 26,435

¹Estimated. ²Revised. W Withheld to avoid disclosing company proprietary data.

³Recoverable vanadium contained in uranium and vanadium ores and concentrates received at mills, plus vanadium recovered from ferrophosphorus derived from domestic phosphate rock.

⁴Produced directly from all domestic ores and ferrophosphorus slag; includes metavanadates.

⁵Includes vanadium recovered from fly ash, residues, and spent catalysts.

⁶May include ores and concentrates.

⁷Excludes U.S. production.

TABLE 2
CHEMICAL SPECIFICATIONS FOR COMMERCIAL FORMS OF FERROVANADIUM

Alloy	Composition, maximum weight-percent							
	Vanadium	Carbon	Nitrogen	Aluminum	Silicon	Phosphorus	Sulfur	Manganese
50% to 60% ferrovanadium	50.0-60.0	0.2	—	2.0	1.0	0.05	0.05	—
70% to 80% ferrovanadium	70.0-80.0	—	—	1.0	2.5	.05	.10	—
80% ferrovanadium	77.0-83.0	.5	—	.5	1.25	.05	.05	.50
proprietary alloys:								
Carvan (Stratcor)	82.0-86.0	10.5-14.5	—	.1	.10	.05	.10	.05
Ferovan (Shieldalloy)	42.0 min.	.85	—	—	7.0	—	—	4.50
Nitrovan (Stratcor)	78.0-82.0	10.0-12.0	6.0 min.	.1	.1	.05	.01	.05

TABLE 3
U.S. IMPORT DUTIES, JANUARY 1, 1991

Tariff item ¹	HTS No.	Most favored nation (MFN)	Non-MFN
Ores and concentrates	2615.90.6090	Free	Free.
Slag	2619.00.9030	Free	Free.
Ash and residues	2620.50.0000	Free	Free.
Vanadium pentoxide anhydride	2825.30.0010	16.0% ad valorem	40% ad valorem.
Vanadium oxides and hydroxides, other	2825.30.0050	16.0% ad valorem	40% ad valorem.
Vanadates	2841.90.1000	11.2% ad valorem	40% ad valorem.
Ferrovandium	7202.92.0000	4.2% ad valorem	25% ad valorem.
Aluminum-vanadium master alloys	7601.20.9030	Free	10.5% ad valorem.
Waste and scrap	8112.40.3000	Free	Free.

¹Specific import classes only.

TABLE 4
STOCKPILE STATUS, DECEMBER 31, 1991

(Metric tons of contained vanadium)

Material	Goal	Inventory
Vanadium pentoxide	6,985.00	654.00
Ferrovandium	907.00	—

TABLE 5
COMPOSITION LIMITS FOR VANADIUM PENTOXIDE PURCHASED FOR THE NATIONAL DEFENSE STOCKPILE

Material		Percent by weight (dry basis)	
		Grade A	Grade B
Vanadium pentoxide (V ₂ O ₅)	Minimum	98.0	98.0
Phosphorus (P)	Maximum	.05	.05
Sulfur (S)	do.	.04	.04
Silica (SiO ₂)	do.	.50	.25
Arsenic (As)	do.	.05	.03
Iron (Fe)	do.	.20	.15
Total alkali (Na + K)	do.	.75	.50
Boron (B)	do.	—	.005
Chromium (Cr)	do.	—	.10
Copper (Cu)	do.	—	.05
Lead (Pb)	do.	—	.01
Manganese (Mn)	do.	—	.05
Molybdenum (Mo)	do.	—	.10
Nickel (Ni)	do.	—	.05
Nitrogen (N)	do.	—	.05
Silicon (Si)	do.	—	.12
Tungsten (W)	do.	—	.01
Uranium (U ₃ O ₈)	To be determined and reported		

NOTE.—If the weight percent of U₃O₈ is less than 0.71 and the radioactivity is essentially evenly distributed, it is not considered radioactive in terms of Department of Transportation requirements. If the weight percent of U²³⁵ in the U₃O₈ is in excess of 0.05 weight-percent, then it is considered a radioactive material according to the Nuclear Regulatory Commission, and CFR 10, Parts 20, 40, and 70 apply.

TABLE 6
U.S. VANADIUM PENTOXIDE PRODUCERS

Producer	Plant location	Capacity (metric tons pentoxide per year)
AMAX Metals Recovery Corp.	Braithwaite, LA	1,800
Gulf Chemical & Metallurgical Corp.	Freeport, TX	1,400
Kerr McGee Chemical Corp.	Soda Springs, ID	2,000
UMETCO Minerals Corp.	Blanding, UT	6,800
U.S. Vanadium Corp.	Hot Springs, AR	6,800

TABLE 7
**U.S. CONSUMPTION AND CONSUMER STOCKS OF VANADIUM
 MATERIALS, BY TYPE**

(Kilograms of contained vanadium)

Type	1990		1991	
	Consumption	Ending stocks	Consumption	Ending stocks
Ferrovandium ¹	'3,445,849	'290,323	2,888,099	301,122
Oxide	17,017	14,047	16,459	12,723
Ammonium metavanadate	W	W	W	W
Other ²	'618,295	'46,057	380,805	48,992
Total	'4,081,161	'350,427	3,285,363	362,837

¹Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."

²Includes other vanadium-iron-carbon alloys as well as vanadium oxides added directly to steel.

³Consists principally of vanadium-aluminum alloy and small quantities of other vanadium alloys and vanadium metal.

TABLE 8
U.S. CONSUMPTION OF VANADIUM IN 1991, BY END USE

(Kilograms of contained vanadium)

End use	Quantity
Steel:	
Carbon	919,114
Stainless and heat resisting	36,701
Full alloy	739,406
High-strength low-alloy	919,496
Tool	241,963
Unspecified	W
Total¹	2,856,678
Cast irons	15,282
Superalloys	14,348
Alloys (excluding steels and superalloys):	
Cutting and wear-resistant materials	W
Welding and alloy hard-facing rods and materials	5,994
Nonferrous alloys	W
Other alloys ²	350,476
Chemical and ceramic uses:	
Catalysts	9,340
Other ³	W
Miscellaneous and unspecified	33,245
Grand total	3,285,363

W Withheld to avoid disclosing company proprietary data, included with "Miscellaneous and unspecified."

¹Data may not add to totals shown because of independent rounding.

²Includes magnetic alloys.

³Includes pigments.

TABLE 9
PRODUCERS OF VANADIUM ALLOYS OR METAL
IN THE UNITED STATES IN 1991

Producer	Plant location	Products ¹
Bear Metallurgical, Inc.	Butler, PA	FeV.
KB Alloys Inc.	Henderson, KY	VAI, ZrVAI.
Do.	Wanatchee, WA	Do.
Reading Alloys Inc.	Robesonia, PA	NiV, VAI, V.
Shieldalloy Metallurgical Corp.	Cambridge, OH	FeV, Ferovan. ²
Do.	Newfield, NJ	FeV.
Strategic Minerals Corp.	Niagara Falls, NY	FeV, VAI, Nitrovan. ²
Teledyne Wah Chang Albany	Albany, OR	V, VAI.

¹FeV, ferrovandium; V, vanadium metal; VAI, vanadium-aluminum alloy; ZrVAI zirconium-vanadium-aluminum alloy; NiV nickel-vanadium alloy.

²Registered trademarks for proprietary products.

TABLE 10
COUNTRIES OF ORIGIN OF VANADIUM RAW MATERIALS

Material	Principal producing countries
Ash and residues	Canada, Germany, Italy, Mexico, Venezuela.
Spent catalysts	Canada, Netherlands.
Vanadium-bearing slag	Republic of South Africa.

TABLE 11
U.S. EXPORTS OF VANADIUM IN 1991, BY COUNTRY

Country	Ferrovanadium (gross weight)		Aluminum-vanadium master alloy ¹ (gross weight)		Vanadium compounds (contained weight)			
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Pentoxide (anhydride) ²		Other ³	
					Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Argentina	—	—	—	—	418	\$22	499	\$11
Australia	—	—	—	—	363	6	—	—
Austria	—	—	—	—	44,828	265	19,051	114
Belgium	2,129	\$24	1,000	\$4	132,363	655	657,716	3,602
Brazil	—	—	137	6	71,517	405	—	—
Canada	122,165	1,538	53,426	1,706	—	—	313,162	2,047
Costa Rica	—	—	293	8	—	—	—	—
Chile	268	4	—	—	22,988	100	—	—
El Salvador	—	—	180	6	—	—	—	—
Egypt	—	—	—	—	—	—	33,725	76
France	—	—	912	114	18,657	194	19,361	54
Germany	—	—	147	12	1,890	102	—	—
Hong Kong	—	—	135	4	—	—	—	—
India	—	—	50	14	—	—	—	—
Italy	—	—	840	28	—	—	—	—
Jamaica	—	—	—	—	1,033	43	—	—
Japan	—	—	23,545	205	251,305	1,424	7	4
Korea, Republic of	—	—	1,103	28	—	—	—	—
Malaysia	397	8	—	—	—	—	—	—
Mexico	40,336	678	72,028	1,927	57,158	546	18,859	134
Netherlands	—	—	119	3	77,012	564	—	—
Nigeria	—	—	—	—	—	—	1,633	33
Norway	—	—	938	4	—	—	—	—
Pakistan	—	—	—	—	1,452	22	—	—
Philippines	—	—	6,125	29	—	—	—	—
Portugal	—	—	—	—	—	—	8,132	27
Saudi Arabia	—	—	—	—	—	—	9,768	104
Spain	—	—	2,757	91	—	—	—	—
Switzerland	—	—	132	7	19,051	114	—	—
Taiwan	5,567	82	680	38	—	—	9,792	63
Thailand	—	—	—	—	—	—	11,394	171
United Kingdom	—	—	5,845	108	—	—	6,812	50
Venezuela	7,165	121	—	—	204	3	—	—
Total ⁴	178,027	2,454	170,392	4,344	700,239	4,466	1,109,911	6,491

¹May include vanadium metal.

²May include catalysts containing vanadium pentoxide.

³Excludes vanadates.

⁴Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 12
U.S. IMPORTS OF FERROVANADIUM, BY COUNTRY

Country	1990			1991		
	Gross weight (kilograms)	Vanadium content (kilograms)	Value (thousands)	Gross weight (kilograms)	Vanadium content (kilograms)	Value (thousands)
General imports:						
Austria	116,200	94,534	\$1,391	120,000	94,415	\$1,236
Belgium	36,021	28,284	250	101,000	78,803	932
Canada	125,401	100,566	1,737	160,552	130,543	1,796'
China	17,355	14,003	210	—	—	—
Czechoslovakia	—	—	—	86,014	70,257	847
France	—	—	—	20,000	16,301	197
Germany, Federal Republic of	22,536	16,896	283	7,000	5,698	66
Japan	5,000	3,970	59	—	—	—
United Kingdom	—	—	—	39,000	31,747	389
Total¹	322,513	258,253	3,930	533,566	427,764	5,464
Imports for consumption:						
Austria	116,200	94,534	1,391	138,000	109,049	1,409
Belgium	36,021	28,284	250	91,000	70,612	837
Canada	125,401	100,566	1,737	160,552	130,543	1,796'
Czechoslovakia	—	—	—	86,014	70,257	847
France	—	—	—	20,000	16,301	197
Germany, Federal Republic of	22,536	16,896	283	7,000	5,698	66
Japan	5,000	3,970	59	—	—	—
United Kingdom	—	—	—	21,000	17,113	214
Total¹	305,158	244,250	3,720	523,566	419,573	5,367

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 13
U.S. IMPORTS OF VANADIUM PENTOXIDE (ANHYDRIDE), BY COUNTRY

Country	1990			1991		
	Gross weight (kilograms)	Vanadium content (kilograms)	Value (thousands)	Gross weight (kilograms)	Vanadium content (kilograms)	Value (thousands)
General imports:						
Canada	825	429	\$3	56,855	30,706	\$102
France	20	19	3	27	20	3
Germany, Federal Republic of	2,049	1,290	52	999	559	27
South Africa, Republic of	71,000	46,988	444	148,520	113,669	905
United Kingdom	34,000	33,901	217	10	3	4
Total¹	107,894	82,627	719	206,411	144,957	1,042
Imports for consumption:						
Canada	825	429	3	56,855	30,706	102
France	20	19	3	27	20	3
Germany, Federal Republic of	2,049	1,290	52	999	559	27
South Africa, Republic of	71,000	46,988	444	133,480	101,616	807
United Kingdom	34,000	33,901	217	10	3	4
Total¹	107,894	82,627	719	191,371	132,904	943

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 14
U.S. IMPORTS OF VANADIUM-BEARING ASH, RESIDUES,
AND OTHER MATERIALS, BY COUNTRY¹

Material and country	1990			1991		
	Gross weight (kilograms)	Vanadium pentoxide content (kilograms)	Value (thousands)	Gross weight (kilograms)	Vanadium pentoxide content (kilograms)	Value (thousands)
Slag:²						
Chile	28,213,536	1,551,744	\$1,232	—	—	—
South Africa, Republic of	7,248,548	1,734,640	5,282	1,326,297	318,311	\$3,066
Total³	35,462,084	3,286,384	6,514	1,326,297	318,311	3,066
Ash and residues:						
Belgium	116,078	73,091	104	—	—	—
Canada	1,084,834	448,860	1,212	679,974	314,314	537
Dominican Republic	—	—	—	52,760	15,828	24
France	15,408	7,319	18	—	—	—
Germany, Federal Republic of	808,740	293,036	165	536,150	107,230	40
Israel	37,860	10,222	34	—	—	—
Italy	1,256,091	292,159	608	286,729	47,027	182
Jamaica	—	—	—	68,181	20,454	120
Mexico	1,513,436	564,228	2,440	246,191	97,210	312
Netherlands Antilles	64,450	14,502	27	350,219	133,949	183
Spain	—	—	—	31,090	4,663	12
United Kingdom	186,308	39,622	52	—	—	—
Venezuela	159,592	58,032	126	68,020	25,508	45
Total³	5,242,797	1,801,071	4,786	2,319,314	766,183	1,456
Other (includes spent catalyst):						
Belgium	29,428	4,402	7	—	—	—
Canada	—	—	—	1,982,781	396,556	219
France	—	—	—	44,723	7,902	17
Italy	209,650	54,958	110	44,435	6,264	25
Japan	333,390	25,262	131	—	—	—
Kuwait	10,483,900	1,538,887	809	—	—	—
Netherlands	481,632	93,378	72	181,611	28,113	27
United Kingdom	1,240,406	26,555	39	218,300	50,678	45
Total³	12,778,406	1,743,442	1,169	2,471,85	489,513	332

¹Revised

²General imports.

³As adjusted by the U.S. Bureau of Mines.

⁴Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 15
WORLD VANADIUM PENTOXIDE
ANNUAL PRODUCTION
CAPACITY, DECEMBER 31, 1991¹

(Metric tons of contained vanadium)

Country	Rated capacity ²
Austria	1,500
Brazil	—
Canada	770
Chile	2,300
China	8,200
South Africa, Republic of	27,200
U.S.S.R.	9,500
United States	11,000
Venezuela	2,500
Other	550
Total	63,520

¹Includes V₂O₅ in vanadiferous iron slags and petroleum refinery residues.

²Includes capacity of operating plants as well as plants on standby basis.

TABLE 16
VANADIUM: WORLD PROCESSING FACILITIES

Country and plant	Location	Vanadium processing				Other ¹
		Vanadium pentoxide	Ferro-vanadium	Ammonium metavanadate	Aluminum-vanadium alloy	
United States:						
Akzo Chemical Co.	Weston, MI					E
AMAX Metals Recovery Corp.	Braithwaite, LA	x				
Bear Metallurgical Corp.	Butler, PA		x			
Cotter Corp.	Canon City, CO	x				
Gulf Chemical & Metallurgical Corp.	Freeport, TX	x				
Kerr-McGee Chemical Corp.	Soda Springs, ID	x		x		
Reading Alloys Inc.	Robesonia, PA				x	C
Shieldalloy Metallurgical Corp.	Cambridge, OH		x	x	x	B, E
U.S. Vanadium Corp.	Hot Springs, AR	x				
Do.	Niagara Falls, NY		x		x	A, E
Teledyne Wah Chang	Albany, OR					C, D
Umetco Minerals Corp.	Blanding, UT	x				
Canada:						
Carbovan Inc.	Fort McMurray, Saskatchewan	x				
Masterloy Products Ltd.	Gloucester, Ontario		x			
Germany, Federal Republic of:						
Gesellschaft fur Electrometallurgie mbH	Nuremberg		x		x	
Belgium:						
Sadacem (Langerbruggekaai Plant)	Ghent		x			
Spain:						
Ferroastur SA	Poligono de Maqua, Aviles		x			
Sweden:						
Metals & Powders						
Trollhatten AB (Sandvik AB)	Trollhatten		x			
United Kingdom:						
Ferroalloys & Metals Ltd.	Glossop, Derbyshire		x			
London & Scandinavian Metallurgical Co. Ltd.	Rotherham, South Yorkshire		x			
Murex Ltd.	Rainham, Essex	x	x	x		
South Africa, Republic of:						
Highveld Steel & Vanadium Corp.	Witbank	x		x		
Transvaal Alloys Pty. Ltd.	Roos Senekal, Transvaal	x				
Union Steel Corp.	Vereeniging	x				
Vametco Minerals Corp.	Bushveld Complex	x		x		A
Vansa Vanadium SA Ltd.	Steelpoort, Eastern Transvaal					
Japan:						
Awamura Metals Industry Co.	Uji, Kyoto		x			
Japan Metals and Chemical Co.	Oguni, Yamagata		x			
Nippon Denko KK	Hokuriku, Toyama		x			
NKK Corp.	Toyama, Toyama		x			
Shinko Chemical Co. Ltd.	Saki, Osaka	x				
Taiyo Mining & Industrial Co.	Ako, Hyogo	x	x			
China:						
Chengde Plant	Hebei	x				
Emei Ferroalloy Plant	Sichuan		x			
China Titanium Plant	Zunyi, Guizhou	x				
Jinzhou Ferroalloy Plant	Liaoning	x	x			

See footnotes at end of table.

TABLE 16—CONTINUED
VANADIUM: WORLD PROCESSING FACILITIES

Country and plant	Location	Vanadium processing				
		Vanadium pentoxide	Ferro-vanadium	Ammonium metavanadate	Aluminum-vanadium alloy	Other ¹
China—Continued:						
Nanjing Ferroalloy Plant	Jiangsu	x	x			
Shanghai Plant	Shanghai		x			
U.S.S.R.:						
Chusovskoy Metallurgical Zavod	Chusovoy	x	x			
Novo-Tagilskiy	Nizhniy-Tagil	x	x			
Novo-Tulskiy Metallurgical Zavod	Tula	x	x			
Serovskiy Metallurgical Zavod	Serov	x	x			

¹A, Nitrovan, proprietary product; B, Ferovan, proprietary product; C, Vanadium metal producer; D, Vanadium-zirconium alloy producer; and E, Unsupported vanadium catalyst.

TABLE 17
VANADIUM: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons of contained vanadium)

Country	1987	1988	1989	1990	1991 ^a
Production from ores, concentrates, slag:²					
China (in vanadiferous slag product) ^a	4,500	4,500	4,500	4,500	4,500
South Africa, Republic of: ³					
Content of pentoxide and vanadate products ^a	5,842	6,331	7,267	7,106	5,000
Content of vanadiferous slag product ^{a 4}	10,100	11,300	11,300	10,000	8,435
Total	15,942	17,631	18,567	17,106	13,435
U.S.S.R. ^a	9,600	9,600	9,600	9,000	8,500
United States (recoverable vanadium)	W	W	W	W	W
Total⁶	30,042	31,731	32,667	30,606	26,435
Production from petroleum residues, ash, spent catalysts:⁷					
Japan (in vanadium pentoxide product) ^a	728	728	889	889	889
United States (in vanadium pentoxide and ferrovandium products)	2,275	2,950	2,389	2,308	2,250
Total	3,003	3,678	3,278	3,197	3,139
Grand total	33,045	35,409	35,945	33,803	29,574

^aEstimated. W Withheld to avoid disclosing company proprietary data; not included in "Total."

¹In addition to the countries listed, vanadium is also recovered from petroleum residues in Germany, the U.S.S.R., and several other European countries, but available information is insufficient to make reliable estimates. Table includes data available through July 9, 1992.

²Production in this section is credited to the country that was the origin of the vanadiferous raw material.

³Includes production for Bophuthatswana.

⁴Data on vanadium content of vanadium slag are estimated on the basis of a reported tonnage of vanadium-bearing slag (gross weight) multiplied by an assumed grade of 14.1% vanadium.

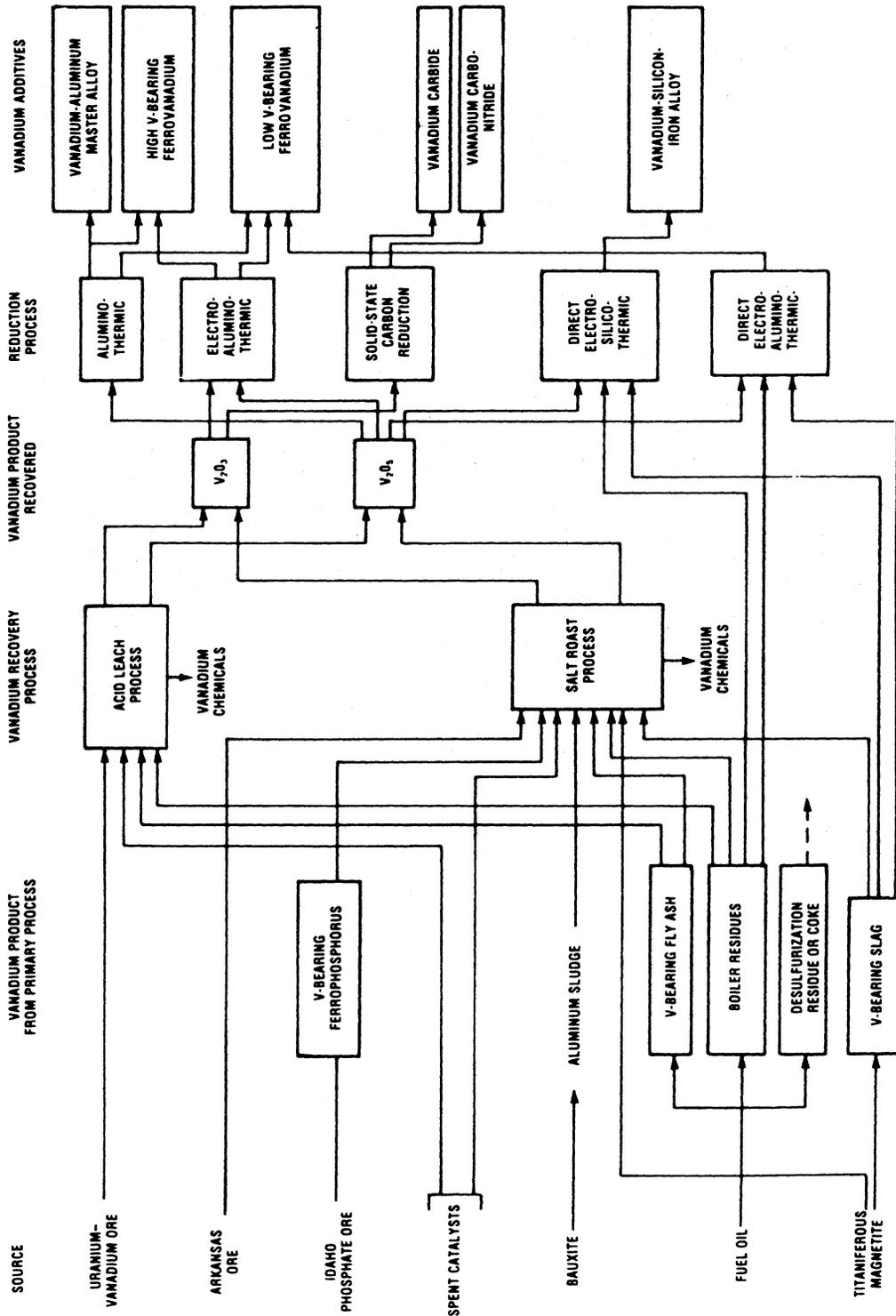
⁵Reported figure.

⁶Excludes U.S. production.

⁷Production in this section credited to the country where the vanadiferous product is extracted; available information is inadequate to permit crediting this output back to the country of origin of the vanadiferous raw material.

GENERALIZED FLOWSHEET FOR THE PROCESSING OF VANADIFEROUS RAW MATERIALS

FIGURE 1



VERMICULITE

By Michael J. Potter

Mr. Potter, a physical scientist, has been the commodity specialist for vermiculite since 1989. Domestic survey data were prepared by Tonya Hardin, statistical assistant; and the international data table was prepared by Brad Colquitt, international data coordinator.

Vermiculite is a micaceous mineral that rapidly expands upon heating to produce a low-density material. The expanded (exfoliated) product is used as lightweight aggregate and thermal insulation in construction applications; as a fertilizer carrier and soil conditioner in agriculture; and as a filler and texturizer for plastics and rubber, among many other uses.

DOMESTIC DATA COVERAGE

Domestic production data for vermiculite were developed by the Bureau from two separate, voluntary surveys, one for domestic mine operations and the other for exfoliation plant operations. Of the five known mine-mill operations (including one dismantled) to which a survey request was sent, data or estimated data were received from three operations by the canvass closeout date. Data for the two nonrespondents were estimated by the U.S. Bureau of Mines. Of the 31 known active exfoliating plants to which a survey request was sent, data were obtained from 26. This represented 63% of the total exfoliated vermiculite sold and used shown in table 1. The five nonrespondents' data were estimated by the Bureau using previous years' production levels. (See table 1.)

PRODUCTION

U.S. vermiculite concentrate sold and used was 185,000 short tons, a decrease from that of the previous year, according to the U.S. Bureau of Mines. The tonnage of exfoliated vermiculite sold and used was 150,000 tons, also a decrease from that of 1990. Construction activity continued to be at a reduced level,

lowering demand for vermiculite in that market sector.

W.R. Grace & Co. was believed to have been the largest domestic producer of vermiculite concentrate with sales of material from its Libby, MT, location (from stockpiles) and from its operation at Enoree, SC. Other producers during the year were Virginia Vermiculite Ltd., near Woodruff, SC, and in Louisa County, VA, and Patterson Vermiculite Co., Enoree, SC. South Carolina, with three operations, was the leading producing State for the fifth consecutive year.

Domestic sales of exfoliated vermiculite by 14 known producers came from 31 plants in 19 States. Of these plants, 20 in 16 States were operated by W.R. Grace. In descending order of output sold and used, the principal exfoliated vermiculite-producing States were estimated to be Ohio, South Carolina, Pennsylvania, New Jersey, California, Illinois, and Arkansas. (See tables 2 and 3.)

FOREIGN TRADE

Imports of vermiculite concentrate, an estimated 42,000 tons, were mainly from the Republic of South Africa.

WORLD REVIEW

The data in table 4 are rated annual capacity for vermiculite plants as of December 31, 1991. Rated capacity is defined as the maximum quantity of product that can be produced at a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine

operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgement of the author, can be brought into production within a short period of time with minimum capital expenditure. Plant capacity for vermiculite is based on engineering capacity provided by the companies or estimated by considering recent peak production during the past 5 years to be equal to rated capacity.

In Australia, Helix Resources NL was evaluating a vermiculite deposit at Bulbodney Creek, New South Wales. Drilling showed a measured resource of 770,000 tons of ore containing approximately 40% vermiculite. Testing thus far had indicated the absence of asbestos fibers.¹ (See tables 4 and 5.)

CURRENT RESEARCH

Sanitech, Inc. was testing a pilot circuit at a powerplant in Lorain, OH, to remove SO₂, NO_x, and residual particulates from flue gas. Granular sorbents containing magnesia and exfoliated vermiculite were being utilized. Regeneration would yield elemental sulfur, SO₂, and H₂S as byproducts.²

OUTLOOK

Some end uses of vermiculite, such as concrete and premixes, have been affected by a sluggish construction market and by substitute materials in recent years. The demand for vermiculite in agricultural uses in the near future should remain steady or show moderate growth. This is a reflection of new potting soils,

lawn care products, etc., and continuing interest in gardening and horticulture.

¹Industrial Minerals (London). Mineral Notes. No. 289, Oct. 1991, p. 59.

²Hindman, J. R. Vermiculite. Min. Eng., v. 44, No. 6, June 1992, p. 578.

OTHER SOURCES OF INFORMATION

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Mineral Commodity Summaries, annual.

Other Sources

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Mining Engineering, monthly.

Roskill Information Services Ltd. (London).

TABLE 1
SALIENT VERMICULITE STATISTICS

(Thousand short tons and thousand dollars unless otherwise specified)

	1987	1988	1989*	1990	1991	
United States:						
Sold and used by producers:						
Concentrate	303	304	275	230	185	
Value	\$33,100	\$33,900	\$30,500	*\$19,100	W	
Average value ¹	dollars per ton	\$109	\$112	\$111	*\$83	\$72
Exfoliated	252	249	215	157	150	
Value	\$54,600	\$55,100	\$48,800	\$39,400	\$38,600	
Average value ¹	dollars per ton	\$217	\$221	\$227	*\$251	\$257
Exports to Canada	*20	*20	20	*20	*11	
Imports for consumption	32	*35	55	*50	*42	
World: Production ²	726	710	*678	*638	576	

*Estimated. *Revised. W Withheld to avoid disclosing company proprietary data.

¹Based on rounded data.

²Excludes production by countries for which data were not available.

TABLE 2
EXFOLIATED VERMICULITE SOLD AND USED IN THE UNITED STATES, BY END USE

(Short tons)

End use	1990	1991
Aggregates:		
Concrete	29,500	W
Plaster	400	W
Premixes ¹	19,500	W
Total	49,400	32,000
Insulation:		
Loose-fill	14,400	W
Block	19,200	W
Other ²	3,000	W
Total	36,600	35,900
Agricultural:		
Horticultural	20,100	17,600
Soil conditioning	8,100	15,400
Fertilizer carrier ³	35,100	35,300
Total ⁴	63,300	68,300
Other ³	7,400	14,100
Grand total ⁴	157,000	150,000

*Estimated. W Withheld to avoid disclosing company proprietary data; included in "Total."

¹Includes acoustic, fireproofing, and texturizing uses.

²Includes high-temperature and packing insulation and sealants.

³Includes various industrial, etc., uses not specified.

⁴Data do not add to totals shown because of independent rounding.

TABLE 3
ACTIVE VERMICULITE EXFOLIATING PLANTS IN THE UNITED STATES IN 1991

Company	County	State
A-Tops Corp.	Beaver	Pennsylvania.
Brouk Co.	St. Louis	Missouri.
W. R. Grace & Co., Construction Products Div.	Jefferson	Alabama
Do.	Maricopa	Arizona.
Do.	Alameda	California.
Do.	Orange	Do.
Do.	Broward	Florida.
Do.	Hillsborough	Do.
Do.	Du Page	Illinois.
Do.	Campbell	Kentucky.
Do.	Prince Georges	Maryland.
Do.	Hampshire	Massachusetts.
Do.	Mercer	New Jersey.
Do.	Multnomah	Oregon.
Do.	Lawrence	Pennsylvania.
Do.	Greenville ¹	South Carolina.
Do.	Dallas	Texas.
Koos Inc.	Kenosha	Wisconsin.
Patterson Vermiculite Co.	Laurens	South Carolina.
James River Limestone Co., Inc.	Fluvanna	Virginia.
The Schundler Co.	Middlesex	New Jersey.
O.M. Scott & Sons	Union	Ohio.
Southwest Vermiculite Co., Inc.	Bernalillo	New Mexico.
Strong-Lite Products Corp.	Jefferson	Arkansas.
Do.	Lesalle	Illinois.
Thermo-O-Rock, Inc.	Maricopa	Arizona.
Do.	Washington	Pennsylvania.
Verlite Co.	Hillsborough	Florida.
Vermiculite Industrial Corp.	Allegheny	Pennsylvania.
Vermiculite Products Inc.	Harris	Texas.

¹Two plants in county.

TABLE 4
WORLD VERMICULITE ANNUAL PRODUCTION CAPACITY,
DECEMBER 31, 1991

(Thousand short tons)

Country	Rated capacity ^{1 2}
North America:	
Mexico	1
United States	185
Total	<u>186</u>
South America:	
Argentina	21
Brazil	28
Total	<u>49</u>
Europe:	
U.S.S.R.	107
Africa:	
Egypt	1
Kenya	4
South Africa, Republic of	252
Total	<u>257</u>
Asia:	
India	4
Japan	17
Total	<u>21</u>
World total	<u>620</u>

¹Includes capacity at operating plants as well as at plants on standby basis.

²Excludes countries for which data were not available.

TABLE 5
VERMICULITE: WORLD PRODUCTION, BY COUNTRY¹

(Short tons)

Country ²	1987	1988	1989	1990	1991 ³
Argentina	20,516	21,275	650	11,000	11,000
Brazil	18,546	20,732	22,623	27,558	27,560
Egypt	550	260	300	31	30
India	2,689	4,467	3,047	1,950	2,200
Japan ³	17,000	17,000	17,000	17,000	17,000
Kenya	4,285	4,086	4,189	2,927	2,535
Mexico	177	240	331	146	165
South Africa, Republic of	252,278	230,578	247,469	242,851	236,617
U.S.S.R. ³	107,000	107,000	106,924	105,000	94,000
United States (sold and used by producers)	303,000	304,000	275,000	230,000	185,000
Total	726,041	709,638	677,532	638,462	576,108

¹Estimated. ²Revised.

¹Excludes production by countries for which data are not available and for which general information is inadequate for formulation of reliable estimates. Table includes data available through July 13, 1992.

²In addition to the countries listed, Tanzania may produce vermiculite, but available information is inadequate to make reliable estimates of output levels, if any.

³Reported figure.

WOLLASTONITE AND ZEOLITES

By Michael J. Potter and Robert L. Virta

Mr. Potter, a physical scientist, has been the commodity specialist for wollastonite since 1976. Domestic survey data were prepared by Linder Roberts, statistical assistant.

Mr. Virta, a physical scientist with 16 years U.S. Bureau of Mines experience, has been the commodity specialist for natural zeolites since 1986. Domestic survey data were prepared by Linder Roberts, statistical assistant.

WOLLASTONITE

Wollastonite is natural calcium silicate and has a theoretical composition of $\text{CaO} \cdot \text{SiO}_2$. It has developed a significant role as a high-performance mineral filler in paint, plastics, and thermal board. It is used in asbestos replacement and in ceramics such as wall tile, where it promotes low shrinkage, good strength, low warpage, and fast firing.

Domestic sold and used data for wollastonite were developed by the U.S. Bureau of Mines by means of a voluntary survey. Both active operations responded, representing 100% of the total canvassed. Specific data were withheld to avoid disclosing company proprietary data.

The two U.S. producers were NYCO, a division of NYCO Minerals Inc., Essex County, NY, and R. T. Vanderbilt Co. Inc., Lewis County, NY. The tonnage of wollastonite sold or used in 1991 increased compared with that of the previous year.

NYCO approved a \$14 million appropriation to increase its wollastonite production by 50%. The 4-year program was to begin with the modernization and expansion of the company's 40-year-old plant in Willsboro, NY. New primary and secondary crushers would be installed and statistical process control added. NYCO was planning to open a new mine, Oak Hill.¹

Wollastonite is used as a filler in ceramic tile, paint, and plastics. It serves as an asbestos replacement in some

applications such as a reinforcement filler for boards and panels in various heat containment applications, including ovens, dryers, thermal ducting, and many other thermal applications. Wollastonite also replaces asbestos in certain cement formulations, in ceilings and floor tile, and in friction applications such as brake linings.

Prices from Industrial Minerals, December 1991, for wollastonite, exworks, converted to dollars per metric ton, were approximately \$278 to \$292 for acicular, minus 200 mesh; \$193 to \$204 for minus 325 mesh; and \$209 to \$215 for minus 400 mesh. Prices per metric ton for wollastonite, f.o.b. plant, bulk, were \$125 to \$177 for 200 mesh and \$235 for 325 mesh.

In Finland, the Partek Group is a major producer of industrial minerals. The company's primary minerals location is at Lappeenranta in southeastern Finland, near the Soviet border. At this site, wollastonite, cement, lime, ground and precipitated calcium carbonate, and mineral wool are produced. Wollastonite and calcium carbonate are coproducts of the same quarry. The ore contains 20% to 24% wollastonite, and the two coproducts are separated by froth flotation. Powder products are available in several sizes ranging from 70 mesh to 635 mesh. For plastics, especially polypropylene and polyamide, surface-treated grades are produced. Iron content averages 0.2% Fe_2O_3 . For filler grades the Fe_2O_3 content is restricted to 0.15%. Exports of wollastonite were approximately 70% to 75% of

production, with principal destinations being France, the Federal Republic of Germany, Italy, and Spain.²

A magnetic separator recently developed by International Process Systems, Inc., of Golden, CO, was said to have solved the problem of limited operating life of the very thin belts used in rare-earth magnetic roll separators. The new separator was developed for dry applications, with five basic magnetic strength levels being offered. Possible applications were said to include fine particles such as wollastonite and numerous other minerals.³

Wollastonite has unique properties, which should lead to continued growth in demand. In wall tile, a major end use, wollastonite promotes low shrinkage and warpage, good strength, and fast firing with decreased gas evolution. In the production of glass and glass fiber, wollastonite reduces energy requirements if used in place of limestone and sand. Another application, slag treatment for the steel industry, was being investigated.⁴ According to one source, growth in specialty surface-modified grades, fine and ultrafine grades, and high aspect ratio grades of wollastonite could exceed 10% annually.⁵

ZEOLITES

Zeolites are hydrated aluminosilicates of the alkaline and alkaline-earth metals. Approximately 40 natural zeolites have been identified over the past 200 years, the most common of which are analcime, chabazite, clinoptilolite, erionite,

ferrierite, heulandite, laumontite, mordenite, and phillipsite. Zeolites are commercially valuable because of their unique ion-exchange, molecular sieving, and catalytic properties.

Commercial zeolite deposits in the United States are associated with the alteration of volcanic tuffs in saline, alkaline lake deposits, and open hydrologic systems. The deposits are in Arizona, California, Idaho, Oregon, Nevada, New Mexico, Texas, Wyoming, and Utah. The major components of these deposits are chabazite, clinoptilolite, mordenite, and phillipsite. Erionite, orthoclase and plagioclase feldspar, montmorillonite, opal, quartz, and volcanic glass may be present in some deposits as minor components. The composition of these deposits was determined by the temperature and pressure of formation and the chemistry of the precursor volcanic glass and altering fluids. When the alteration process went to completion, the zeolite content of portions of some deposits approached 100%.

Conventional mining techniques were used in the mining of natural zeolites. The overburden was removed to permit access to the ore, and the ore was stripped for processing using front-end loaders or tractors equipped with ripper blades. The fractured ore was dried and then crushed using either jaw crushers or roller mills. The crushed ore was packaged directly for shipping or was screened to remove fine material when a granular product was required.

Nine companies mined or sold natural zeolites in the United States in 1991. Clinoptilolite was mined in Arizona, California, Nevada, New Mexico, Oregon, Texas, and Wyoming; chabazite was mined in Arizona. Total domestic production was 28,866 metric tons. Sales were 18,877 tons in 1991, an increase of 21% from that of 1990. (See table 1.)

Natural zeolites were used for pet litter, odor control, animal feed supplement, aquaculture, fertilizer carrier, desiccant, and wastewater cleanup, in decreasing order of consumption. Other applications include chemical carriers, aquarium filters, gas

adsorbents, water purification applications, and oil and/or grease adsorbent. The properties that made natural zeolites commercially valuable included ammonium adsorption (aquaculture, aquarium filters, odor control applications, pet litter, and water purification), moisture adsorption (desiccants, odor control, and pet litter), and ion-exchange capabilities (wastewater cleanup).

On November 5, 1991, the Environmental Protection Agency (EPA) issued a final rule under the Toxic Substances Control Act (TSCA) for erionite. Under section 5(a)(2) of TSCA, persons who intend to manufacture, import, or process erionite fiber for any new use must notify EPA at least 90 days before beginning that activity. EPA's decision is based on the results of animal inhalation and injection studies and epidemiological studies. The animal studies indicated that fibrous erionite was more potent than crocidolite asbestos for inducing malignant mesothelioma, a rare form of cancer. As a result of these studies, EPA classified fibrous erionite as a Category B1 or probable human carcinogen.⁶

The U.S. Bureau of Mines continued its research at the Reno Research Center on the removal of metals and other cations from water using natural zeolites. The ion-exchange capacities for 24 natural zeolite samples were determined for cadmium, copper, lead, nickel, and zinc. These samples were composed of chabazite, clinoptilolite, erionite, mordenite, and phillipsite. For cadmium, capacities ranged from 0.4 to 2.3 milliequivalents per gram; for copper, 0.33 to 2.73; for lead, 0.68 to 2.51; for nickel, 0.081 to 0.98; and for zinc, 0.12 to 1.68. Phillipsite had the largest exchange capacity for cadmium, copper, and lead. Erionite had the largest exchange capacity for zinc. Exchange tests for nickel are in progress. For low-ion concentration wastewater, phillipsite was found to be the most effective ion exchanger, reducing ion levels for aluminum, cobalt, copper, iron, manganese, and zinc to less than 1% of their original concentrations. The pH of

the solution increased from 1.8 to 8.5 after treatment. For high-ion concentration wastewater, clinoptilolite was the most effective zeolite tested, although the reduction in ion concentrations was significantly less than for low-ion concentration wastewaters. In another part of the research, attrition rates were tested. Samples containing chabazite exhibited the highest attrition. Samples containing clinoptilolite, erionite, and phillipsite exhibited the lowest attrition rates. Attrition rates are an important consideration for zeolite applications.

With the concern over the health risk posed by fibrous erionite increasing, there has been more interest in improving the methods of detection and quantification of this zeolite. Research conducted showed that erionite could be detected in tuffaceous rocks at levels of 100 parts per million to 500 parts per million using X-ray diffraction analysis. The low detection limits were accomplished by the use of long count times, profile fitting of the peaks, incident-beam Soller slits, and solvation of smectites with ethylene glycol. Count rates were increased by a factor of three when a solid-state silicon detector was used in place of the scintillation detector and monochromator system. Additionally, low-angle scatter of X-rays was reduced through the use of a helium atmosphere sample cell. These methods were applied to samples obtained from central Turkey. The detection and quantification of erionite in these tuffs was improved compared to estimates made using scanning electron microscopy. Tuffaceous samples from Yucca Mountain, Nevada, a possible site for a high-level radioactive water repository, were characterized to determine the distribution of erionite in the deposit.⁷

Paragon Resources NL obtained interests in several zeolite deposits in Lampung Province, Sumatra. One deposit near Mount Ratai is a high-purity clinoptilolite deposit. The company is testing the zeolite as an animal feed supplement and for odor control. Paragon Resources also has interests in two deposits near Panjang. One of the

deposits currently is being mined and sold for aquacultural applications.⁸

A method for determining reactions that occur within the zeolite structure was investigated. $\text{Mo}^{(12\text{CO})}_6$ was exchanged within the structure of zeolite Y, a large cavity zeolite, and the zeolite was annealed to equilibrate the system. ^{13}C O or $\text{P}(\text{CH}_3)_3$ was diffused into the cavity of the zeolite structure. The reaction between the $\text{Mo}^{(12\text{CO})}_6$ and the ^{13}C O or $\text{P}(\text{CH}_3)_3$ was observed using Fourier transform infrared spectroscopy to determine the reaction kinetics and mechanism. In one proposed mechanism, the $\text{Mo}^{(12\text{CO})}_6$ was released as a free molecule when excess $\text{P}(\text{CH}_3)_3$ was introduced into the α -cage of the zeolite structure. The attachment of the $\text{P}(\text{CH}_3)_3$ to the sodium ions lining the α -cage was thought to have caused the release of the $\text{Mo}^{(12\text{CO})}_6$. In the process of reattaching to the sodium ions, the $\text{Mo}^{(12\text{CO})}_6$ lost two CO ligands. The $\text{P}(\text{CH}_3)_3$ replaced the two lost ligands. The study demonstrated that kinetics studies of chemical reactions occurring in zeolite cavities is feasible.⁹

Research was conducted on recycling polypropylene using a zeolite catalyst. Polypropylene pellets were mixed with the synthetic zeolite H-ZSM-5 and heated to 350° C for 2 hours in a sealed vessel. The reaction products included C1 to C7 hydrocarbons, such as benzene, hexane, methane, propane, toluene, and xylene. A large portion of the reaction products were C3 and C4 hydrocarbons, which are components of gasoline.¹⁰

The synthetic zeolite industry continues to expand mainly in response to environmental concerns. J.M. Huber Corp. announced plans that it will reenter the synthetic zeolite field after an absence of several years.¹¹ Crosfield Chemicals announced that it would build a 55-thousand-ton-per-year zeolite facility in Illinois for detergent applications while Ethyl Corp. planned an expansion of its Houston plant.¹² PQ Corp. announced plans to build zeolite detergent plants in Georgia and Indiana.¹³

¹Industrial Minerals (London). NYCO Starts \$14 Million Wollastonite Expansion. No. 284, May 1991, p. 13.

²Benbow, J. Finland's Mineral Industry. Ind. Miner. (London), No. 283, Apr. 1991, pp. 21, 22.

³Mining Magazine. High-Force Magnetic Separator. V. 164, No. 3, Mar. 1991, p. 176.

⁴Rieger, K. C. Wollastonite. Am. Ceram. Soc. Bull., v. 70, No. 5, May 1991, p. 888.

⁵Bauer, R. R. Wollastonite. Min. Eng., v. 42, No. 6, June 1990, p. 582.

⁶Federal Register. Erionite Fiber; Significant New Use of a Chemical Substance. V. 56, No. 214, Nov. 5, 1991, pp. 56470-56472.

⁷Bish, K., and S. Chipera. Detection of Trace Amounts of Erionite Using X-Ray Powder Diffraction: Erionite in Tuffs of Yucca Mountain, Nevada, and Central Turkey. Clays and Clays Minerals, v. 39, No. 4, 1991, pp. 437-445.

⁸Industrial Minerals (London). Paragon in Zeolite Exploration. No. 291, Dec. 1991, p. 11.

⁹Dagani, R. Scientists Get First Look at Reaction Kinetics Inside Zeolite. Chem. & Eng. News, v. 69, No. 25, June 24, 1991, pp. 21-23.

¹⁰European Chemical News. PP-to-Gasoline Route Promising. V. 57, No. 1508, Feb. 24, 1992, p. 21.

¹¹Chemical Marketing Reporter. Huber's Plan for Zeolites the Latest in Capacity Blitz. V. 240, No. 8, Aug. 19, 1991, p. 3.

¹²———. Crosfield Crosses Over to Detergent Zeolites. V. 239, No. 6, Feb. 11, 1991, p. 20.

¹³Industrial Minerals (London). PQ Corp. Expands Zeolites Further. No. 284, May 1991, p. 13.

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Chemical Marketing Reporter, weekly.
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European Chemical News, weekly.
Industrial Minerals (London), monthly.
Mining Engineering, monthly.

**TABLE 1
DOMESTIC ZEOLITE
PRODUCERS, 1991**

State and company	Type of zeolite
Arizona:	
GSA Resources Inc.	Chabazite.
UOP Inc.	Do.
Non Scents	Clinoptilolite.
California:	
Steelhead Specialty Minerals	Do.
Nevada:	
East-West Minerals Inc.	Do.
New Mexico:	
St. Cloud Mining Co.	Do.
Oregon:	
Teague Mineral Products Co.	Do.
Texas:	
Zeotech Corp.	Do.
Wyoming:	
U.S. Zeolites	Do.

ZINC

By James H. Jolly

Mr. Jolly is a physical scientist (geologist) with more than 30 years of mining experience, including positions with Hecla Mining Co., Roan Selection Trust, and the U.S. Geological Survey. He has been a mineral commodity specialist for the U.S. Bureau of Mines for 19 years and the zinc specialist for the past 10 years. Domestic survey data were prepared by Tony E. Morris, statistical assistant. International production tables were prepared in collaboration with country specialists in the Bureau's Division of International Minerals.

Zinc is an essential element for human health and for the development and maintenance of modern society. It has been used by man in compounds, alloys, and metal for more than 2,000 years and has been surpassed only by aluminum, copper, and iron in historical quantity used. Zinc uses range from medicines and rubber to metal products. Its main use has been to provide corrosion protection for iron and steel. Since 1982, more than one-quarter million tons of zinc had been used to manufacture U.S. pennies.

The state of the domestic zinc industry was variable in 1991. Zinc mine output was the highest in 25 years, and smelters operated at high-capacity utilization rates. Refinery output was the highest since 1981. However, because of a slowing domestic economy, industrial consumption of zinc declined to its lowest level since 1983. The value of unmanufactured zinc exports, plus scrap, was about \$370 million, the same as that in 1990. Exported zinc concentrates accounted for 60% of the total export value and waste and scrap about 23%. The value of imports of scrap and unmanufactured zinc was \$785 million, down about \$300 million from that of 1990 and \$560 million from that of 1989, owing mainly to reduced demand and lower zinc prices.

Zinc prices tended to decline through midyear, but by yearend had returned to about the same level as at the start of the year. The yearend rise occurred despite rising stock levels and weakening world demand; some analysts attributed the

increase to manipulation of the London Metal Exchange (LME) market.

The figures for world mine and smelter outputs were, respectively, the second highest and third highest on record. In 1991, U.S. mines produced 7.5% of the world zinc output and U.S. smelters produced 5.3% of the world refined metal output. World zinc metal consumption was slightly less than 7 million tons for the second straight year, but nonetheless, 1991 was thought to be the fourth highest consumption year, historically. The United States continued to be the world's largest consumer of zinc metal, consuming about 13.3% of the world total. In 1990 and 1989, respectively, the United States accounted for 14.2% and 14.9% of world zinc metal consumption.

Zinc producers in North America dropped previous pricing mechanisms and adopted LME quotations as the basis for their cash and forward price transactions. The pricing change also led to the establishment of LME warehouses in the United States for good delivery of Special High Grade (SHG) metal registered by the LME.

DOMESTIC DATA COVERAGE

Domestic data for zinc were developed by the U.S. Bureau of Mines from five separate, voluntary surveys of U.S. operations. Typical of these was the "Slab Zinc" consumption survey sent out monthly or annually, depending on consumption quantities; small consumers are canvassed annually. Of the 288 operations to which the survey was sent, 263 responded, representing an estimated

91% of the total reported slab zinc consumption shown for 1991 in tables 1, 16, 17, and 18. Consumption by nonrespondents was estimated using prior-year consumption adjusted for industry trends.

Reported consumption of slab zinc, however, accounts for only 82% of apparent metal consumption. The difference between reported and apparent consumption is mainly the result of company requests over the past decade to be dropped from the canvass for company proprietary reasons or, principally, because of the work force burdens of filling out voluntary forms in addition to the plethora of current mandatory Government forms. To determine the distribution of apparent slab zinc consumption, table 15, the unaccounted for tonnage was prorated, based on known uncanvassed companies and use trends, and added to the reported quantities.

ANNUAL REVIEW

Strategic Considerations

Supply.—U.S. mine and smelter production and capacity can supply only about one-half of domestic zinc requirements in either normal or emergency periods. The domestic ore reserve base is large but could not be tapped adequately until after the first year or so in an emergency condition. Domestic smelter capacity is woefully lacking and by itself would be a limiting factor for increased refined zinc output. Inadequate zinc smelter capacity also

severely limits the Nation's ability to produce strategic and critical zinc byproduct elements such as cadmium, germanium, and indium.

Zinc mine production in Alaska accounts for about one-half of domestic output; however, all of this output is exported. Even if Alaskan zinc concentrates were redirected for U.S. consumption only, little domestic smelting capacity is available to process the material. U.S. mine output greatly exceeds smelter capacity, and in 1991, resulted in the net export of 336,000 tons of zinc in concentrate. An additional strategic factor related to Alaskan output is the fact that more than 80% of the State's production is inaccessible for 9 months of the year because of sea ice.

Although imports constitute a large proportion of U.S. zinc supply, about 60% of the zinc metal, concentrate, and compound imports comes from Canada and Mexico, and, therefore, the risk of supply disruption is low. Other traditional sources of zinc supply depend on sea transport, and the risk of supply disruption is considerably higher.

Stockpile.—A stockpile of zinc for national defense purposes has been maintained by the Government for more than 50 years. Materials in the National Defense Stockpile (NDS), managed by the Department of Defense since July 1988, can be released by the President if deemed necessary for defense or essential civilian purposes.

Just prior to and during World War II, the Government accumulated zinc stocks to ensure adequate supplies for national defense. Concerns related to national security after the war resulted in various stockpiling programs that evolved into the current NDS. The stockpile contained a record-high inventory of 1.44 million metric tons of zinc in 1959, but sales of zinc considered to be in excess of the stockpile goal reduced this inventory to 340,194 tons by the end of 1975. The most recent stockpile goal for zinc, 1.293 million tons, was established in April 1980, but no zinc had been purchased through 1991 to meet this goal. At the end of 1991, the zinc stockpile totaled

343,202 tons, including 2,625 tons of zinc contained in brass. Sharply lower goals for zinc have been proposed in the past few years, but none have been approved.

Production

Mine Production.—U.S. zinc mine output was up slightly despite the closing of five zinc-producing mining operations during the year. One new mine did, however, open early in the year. Formosa Resources Corp. completed underground development and mill construction at the Silver Butte Mine in Oregon and began production in April. Plans called for output of about 4,000 tons each of copper and zinc in concentrate annually from ores grading 3.57% copper, 2.98% zinc, and 1.7 ounces of silver per ton. Zinc output in concentrate was less than 1,000 tons in 1991.

The 20 leading U.S. zinc-producing mines accounted for more than 98% of production, with the 5 leading mines accounting for 60%. Alaska, for the second straight year, was the principal zinc-producing State, followed in order of output, by Tennessee, New York, Missouri, Colorado, and Montana. The leading domestic zinc mine producers were ASARCO Incorporated, Cominco Alaska Inc., Union Zinc Co., and Zinc Corporation of America (ZCA).

The Red Dog Mine in northwestern Alaska and the Greens Creek Mine on Admiralty Island accounted for all of Alaska's zinc production in 1991. The Red Dog Mine, which began operations in late 1989, was owned by NANA Regional Corp., Inc. and leased to Cominco Alaska Inc., a subsidiary of Cominco Ltd., which owns and operates the mining and processing facilities. NANA is paid a royalty that was scheduled to increase after the capital investment plus interest was recovered by the operating company.

In 1991, Cominco Alaska increased Red Dog zinc output almost 19% despite substantial declines in both ore grade and mill recovery. The average grade of zinc in ore milled fell to 22.5% zinc from 26.5% in 1990, whereas the mill

recovery averaged only 68%, down 10% from that of the previous year. The lower recovery was attributed to metallurgical problems associated with variable ore types in the deposit. Procedures were established for mining, sorting, and processing various ore types as the year progressed, but overall recoveries, reportedly, were still at unsatisfactory levels at yearend.

Increased production was the result of processing 60% more ore in 1991. For the year, the company milled 1.45 million tons of ore averaging 22.5% zinc, 6.6% lead, and 3.1 ounces of silver per ton and produced 372,600 tons of zinc concentrate averaging 57.1% zinc, 76,600 tons of lead concentrate averaging 57.2% lead, and 34,100 tons of bulk concentrate averaging 32.8% zinc and 20.9% lead. Ore reserves at yearend were 59.7 million tons averaging 18.4% zinc, 5.5% lead, and 3.0 ounces of silver per ton. An additional 14.2 million tons of lower grade ore was classed as inferred reserves.

The Greens Creek Joint Venture, a consortium 53% owned by RTZ Ltd. through its Kennecott subsidiary, Greens Creek Mining Co., and 47% owned by minority partners—Hecla Mining Co., Exalco Resources Corp., and CSX Alaska Mining Inc.—increased the production and reserves at its Greens Creek silver-zinc-gold-lead mine in 1991. Greens Creek Mining, the mine operator, milled 389,000 tons of ore grading 9.9% zinc, 4.0% lead, 22 ounces of silver per ton, and 0.1 ounce of gold per ton and produced 38,570 tons of zinc, 15,700 tons of lead, 7.8 million ounces of silver, and 37,500 ounces of gold in concentrates. Three types of concentrates—zinc, lead, and bulk zinc-lead—were produced; all were exported to foreign smelters. Exploration during 1991 more than doubled the ore reserves. At yearend, ore reserves were about 12.5 million tons averaging 12.8% zinc, 4.0% lead, 14.6 ounces of silver per ton, and 0.13 ounce of gold per ton.

In Tennessee, zinc was produced at six underground mines by Asarco and two divisions of Union Zinc—Jersey Miniere Zinc Co. (JMZ) and Jefferson City Zinc

Div. Asarco's production at four mines was 67,040 tons of zinc in concentrate, up 4,000 tons from that of 1990. At yearend, ore reserves at the four mines were 5.2 million tons averaging about 3.3% zinc, down slightly from the tonnage and grade reported at the end of 1990.

JMZ began restoration of its Idol zinc mine at Thornhill, TN, and planned to bring it on-stream in the first half of 1992 at an annual production rate of about 12,000 tons of zinc in concentrate. The mine, purchased from Kinghill Mines Inc. in December 1989, was last operated by the New Jersey Zinc Co. in 1981. Ore reserves were estimated to be about 5.5 million tons averaging about 3% zinc.

In Missouri, zinc was produced as a coproduct of lead at nine underground lead mines along the Viburnum Trend by three companies, Asarco, The Doe Run Co., and Cominco American Inc., a subsidiary of Cominco Ltd. According to Asarco's annual reports, zinc output in concentrate at the West Fork Mine was 12,600 tons, down about 600 tons from that of 1990, and at the Sweetwater Mine, production was 1,630 tons, down about 1,550 tons. At yearend, ore reserves at the West Fork Mine were 6.8 million tons averaging 1.37% zinc and 5.7% lead with some copper and silver, and at the Sweetwater Mine, 20.0 million tons of ore averaging 4.9% lead and 0.60% zinc. Zinc output at the Magmont Mine, a joint venture of Cominco American and Dresser Industries Inc., increased over that of 1990 owing to an increase in ore output. According to the Cominco annual report, the Magmont mill processed about 1.02 million tons of ore grading 1.0% zinc, yielding 8,450 tons of zinc in 14,200 tons of concentrate in 1991. Ore reserves continued to decline and were expected to be exhausted in about 3 years. At yearend, ore reserves totaled 2.7 million tons and averaged 8.7% lead, 1.3% zinc, and 0.4% copper.

Doe Run produced about 23,000 tons of zinc in 41,700 tons of zinc concentrate at its six lead mines and four mills in the fiscal year ended October 31. Fiscal 1990 zinc production was about 2,000

tons higher. The production decrease occurred largely because the company, in response to poor lead prices, initiated a program in April to reduce its annual output of lead by 55,000 tons in 1991. At the end of the fiscal year, Doe Run estimated its lead ore reserves to be 71 million tons averaging 4.75% lead; the zinc content in reserves was estimated to be 0.9% and copper, 0.3%.

In Idaho, zinc was produced in the Coeur d'Alene mining district at two mines, one of which, the Bunker Hill Mine at Kellogg, closed early in the year owing to financial problems exacerbated by low lead and zinc prices. In November 1990, The Star Phoenix Mining Co. had closed its leased Star zinc-lead-silver mine in the same district for similar reasons. Hecla increased the quantity of ore milled at its Lucky Friday Mine in 1991 but produced slightly less zinc in concentrate. For the year, the company milled 138,000 tons of ore, producing 2,870 tons of zinc, 17,100 tons of lead, 159 tons of copper, 1.85 million ounces of silver, and 928 ounces of gold in concentrates. Ore reserves declined 17% during the year and at yearend were 399,000 tons grading 12.8% lead, 2.8% zinc, and 15 ounces of silver per ton.

Equinox Resources Ltd. began production at the Van Stone open pit zinc-lead mine near Coville, WA, in April, but temporarily closed the operation in September owing to low lead and zinc prices. Mining ceased in August but the company continued the milling of accumulated stocks of lower grade ores. Equinox planned to bring the mine back on-stream when prices improved. At capacity, the operation was expected to produce 15,000 tons of zinc and 2,000 tons of lead in concentrate annually. Remaining ore reserves were estimated to total 2.5 million tons grading 5.7% zinc and 1.1% lead.

Cyprus Minerals Co. operated its Pinos Altos zinc-copper mine in New Mexico as a zinc mine in 1991 but closed it down in the second half of the year because of high operating costs and low zinc prices. Cyprus planned to convert the mine from a zinc to total copper operation within 6 months from the time of the closure.

Copper production was expected to begin in the first quarter of 1992, but no zinc output was planned. Cyprus produced 2,676 tons of zinc in concentrate in 1991, compared with 3,600 tons in 1990.

In Nevada, Alta Gold Co. discontinued mining at its Ward Mine in March owing to depressed metal prices, but continued milling into May at the Taylor Mill to process the balance of stockpiled ore. According to the company, no production was planned for 1992. In February, Alta Gold acquired 100% of the Taylor Mill and associated mineral properties from NERCO Exploration Co. for \$4.8 million; prior to this, the mill, which is 14 miles east of the Ward Mine, had been leased to Alta Gold. The mine and mill, which were started up in April 1990, operated for almost 1 year before closing. Production of metals in concentrates in 1991 and in 1990 (in parentheses) was as follows: zinc, 4,639 tons (9,488 tons); copper, 368 tons (480 tons); lead, 238 tons (832 tons); silver, 58,300 ounces (100,600 ounces); and cadmium, 27 tons (34 tons). Mine/mill zinc recovery was estimated to be 81%. At yearend, ore reserves totaled 690,000 tons averaging 6.27% zinc, 1.07% copper, 0.87% lead, and 2.3 ounces silver per ton.

In Montana, the Montana Tunnels Mining Co., a subsidiary of Pegasus Gold Inc., mined and milled 3.9 million tons of ore at its Montana Tunnels Mine in 1991; concentrates containing 16,000 tons of zinc, 6,500 tons of lead, 1.17 million ounces of silver, and 62,600 ounces of gold were produced. Zinc recovery was 86% in 1991. At yearend, proven and probable reserves were 27.5 million tons grading 0.61% zinc, 0.24% lead, and 0.32 ounce silver, and 0.021 ounce gold per ton. A mine life of 7 years was anticipated. In April, New Butte Mining Co. ceased operations at its zinc-producing mines at Butte, MT, because of poor metal prices.

In Colorado, zinc was produced as a coproduct of gold-silver operations at the Leadville Unit (managed by Asarco, but jointly owned with the Resurrection Mining Co.) and the Sunnyside Mine (owned by San Juan County Mining Venture, a company composed of Alta

Bay Venture (ABV), 67%, and Washington Mining Co., 33%). At the end of March, Alta Gold Co., 60% owner in ABV, relinquished its interest in the Sunnyside Mine venture to its partner, Echo Bay Mining Co., in exchange for indemnification against liabilities that may have occurred while the company was involved in the Sunnyside operation. In August, San Juan temporarily closed the Sunnyside Mine because of low lead, silver, and zinc prices. At Leadville, Asarco increased zinc output in concentrate to 13,400 tons, up 500 tons from that of 1990. Lead, silver, and gold production also increased, totaling 5,800 tons, 320,000 ounces, and 13,300 ounces, respectively, compared with 4,900 tons, 295,000 ounces, and 10,000 ounces produced in 1990. At yearend, ore reserves were 680,000 tons (down 121,000 tons from yearend 1990) grading 7.87% zinc, 3.64% lead, 1.7 ounces of silver per ton, and 0.08 ounce of gold per ton.

Smelter and Refinery Production.—Refined metal production was up slightly from that of 1990 and was the highest since 1981. Three companies, ZCA, JMZ, and Big River Zinc Co., operated four primary zinc refineries in 1991. Secondary zinc metal was produced at 12 secondary plants from waste and scrap materials; however, the largest producer of secondary zinc metal was ZCA at its primary electrothermic smelter at Monaca, PA. A substantial part of the plant's secondary feed was crude zinc calcine recovered from steelmaking, electric arc furnace (EAF) dust by a sister company, Horsehead Resource Development Co. (HRD). The largest producers of zinc metal at secondary plants were Huron Valley Steel Corp., Interamerican Zinc Co., and Gulf Metals Corp.

ZCA continued to upgrade the zinc production capacity of its Monaca, PA, smelter. Since 1988, about 35,000 metric tons had been added, raising plant capacity to about 136,000 tons in 1991. Most of the added capacity, however,

was expected to be dedicated to the processing of EAF zinc calcine.

The processing of EAF dust gained new urgency in 1991 because the dust, as of August, could no longer be disposed of unless it was treated first. EAF dust containing more than 15% zinc was required to be thermally treated to extract zinc and other components; dust with less than 15% was required to be treated or stabilized before disposal. Some zinc-rich EAF dusts continued to be exported to Mexico for treatment, but most was treated at HRD's plants in Illinois, Pennsylvania, and Tennessee. Two plasma-furnace facilities on-site at steelmaking facilities produced zinc metal from EAF dusts. Several other EAF processing plants were under development or planned. A list of operating and proposed domestic plants and capacities is given in table 10.

HRD signed a 10-year agreement in April with North Star Steel Co. whereby HRD would construct and operate a flame reactor facility at North Star's Beaumont, TX, steel plant to extract zinc from the steel plant's EAF dust. Laclede Steel Co. was constructing a 36,000-ton-per-year EAF-dust-processing facility at Alton, IL. Production was scheduled to start in early 1992.

Proposed amendments to the Resource Conservation and Recovery Act, if enacted, would prohibit the disposal of used tires in landfills and tire monofills without some form of treatment. Further, existing used-tire piles, estimated to contain 3 billion tires, were proposed to be eliminated by the year 2005. Because small amounts of zinc compounds, mainly oxide, are used as activators and accelerators in tire rubber formulations, tire processing could become a significant source of secondary zinc in the future.

In July, Oxford Energy Co. began zinc recovery at a new 30-MW, energy-generating, tire-burning plant in Sterling, CT. Oxford has operated a similar but smaller 15-MW unit at Modesto, CA, since 1988. Both plants generated zinc-rich fly ash which, after upgrading by calcining, was shipped to secondary plants for zinc recovery. At capacity, the

Sterling facility expected to burn up to 10 million tires per year for energy generation. A recovery of about 500 tons of zinc annually was also expected. Oxford was planning to have on-stream two additional tire-burning plants, at Buffalo, NY, and Las Vegas, NV, by 1995.

Zinc Oxide.—Domestic American- and French-process zinc oxide was produced entirely from zinc metal and scrap by eight companies in 1991. All but one company, Eagle Zinc Co. of Hillsboro, IL, produced French-process zinc oxide. Some impure oxide produced at secondary plants was sold directly for use in animal feeds and for agricultural purposes. The principal zinc oxide producers in 1991 were Asarco, Eagle Zinc, North American Oxide Inc., and ZCA. North America Oxide began production of French-process zinc oxide at its new 18,000-ton-per-year oxide plant at Clarksville, TN, in July. In the same month, Pigment and Chemicals Co. permanently closed the Memphis, TN, 18,000-ton-per-year zinc oxide plant operated by its subsidiary, Pasco Zinc Corp. The company cited poor market prospects, excessive North American production capacity, improved tire wear, and the loss of a major oxide market (substitution of metal shot for oxide in the electrogalvanizing process) for the closing of this plant and a plant of similar size in Canada 1 month earlier.

Byproduct Sulfur.—Production of sulfur in byproduct sulfuric acid at primary zinc plants was 136,800 tons, about 2,000 tons higher than production in 1990. Acid production at zinc plants in 1991 was valued at \$17.1 million.

Consumption and Uses

Zinc is found in a great many manufactured products, but its role is not obvious to the public because zinc tends to lose its identity in the products. Zinc-containing products were used extensively in 1991 for construction, transportation, electrical, machinery, and chemical

purposes. Zinc-coated steel sheet, structural shapes, fencing, storage tanks, fasteners, nails, and wire rope were widely used in all types of construction, including transmission and radar towers, industrial plants, culverts, roads, bridges, and airfields. Zinc sacrificial anodes were used to protect ship hulls, offshore drilling rigs, and submerged and buried steelwork, tanks, and pipes. Brass was used as shell casings in ammunition and in tubes, valves, motors, refrigeration equipment, heat exchangers, communication units, and electronic devices. Zinc die-cast parts, such as handles, grilles, bezels, brackets, locks, hinges, gauges, pumps, mounts, and housings, were used extensively in vehicles, machinery, business machines, appliances, household hardware, scientific equipment, and electronic equipment. Zinc dust was used in primers and paints; in alkaline dry cell batteries; in the sherardizing process to protectively coat nuts, bolts, and small parts; for the precipitation of noble metals from solution; and in the zinc industry for the removal of impurities, such as copper, cadmium, and lead, before electrolysis. The metal casings of zinc-carbon dry cell batteries were zinc. In 1991, about 23,000 tons of SHG zinc was used by the U.S. Mint to produce 9.3 billion pennies.

Zinc compounds were used in corrosion-inhibiting paint primers, chemical catalysts, welding and soldering fluxes, fungicides and pharmaceuticals, paints, rubber, phosphors for cathode tubes and radar scopes, ceramics, and additives to lubricating oils and greases. Zinc ferrites were used in electrical devices in transformers, coils, amplifiers, motors, and tuners, and in electronic devices in radio, television, and computers.

Domestic consumption of slab zinc fell about 60,000 tons to slightly more than 0.93 million tons in 1991. Galvanizing and electrogalvanizing, mainly for sheet and strip, continued to be the principal use of zinc metal, consuming an estimated 50%, followed by zinc-base die-cast alloys, 21%; brass alloys, 14%; and other uses, 15%. SHG accounted for about 55% of the reported slab zinc

consumed, followed by Prime Western (PW), 25%; High-Grade (HG), 12%; and other grades, 8%.

Overall, the construction sector of the economy was the largest consumer of zinc, accounting for an estimated 43%, followed by transportation, 20%; machinery, 12%; electrical, 12%; and other, 13%. Zinc metal accounted for about three-fourths of the total zinc in end-use products and zinc chemicals about one-fourth in 1991.

According to the American Iron and Steel Institute, reported shipments of domestically produced galvanized sheet and strip totaled 8.2 million tons, down 0.8 million tons from shipments in 1990. Trends in monthly shipments tended to follow the general trends in the economy, down in the first and fourth quarters of the year and generally up in the second and third quarters. Of the total shipments, electrogalvanized sheet accounted for 23% of the tonnage compared with 21% in 1990. The distribution of total shipments by industry sector in 1991 was as follows: automotive, 41%; service centers, 24%; construction, 18%; and other, including exports, 17%. Exports of galvanized sheet and strip totaled 275,000 tons versus imports of 1.38 million tons.

According to the Bureau of Census, zinc-base alloy die and foundry casting shipments totaled about 175,000 tons, down from 188,000 tons reported in 1990. The decline was attributable to a weaker economy in 1991. Zinc die-cast shipments by weight were estimated to have been equally distributed between automotive, hardware, and other uses.

Zinc consumption in the production of copper-base alloy by brass mills, ingotmakers, and foundries was down about 10,000 tons from that of 1990 according to the Copper Development Association Inc. (CDA). The brass and bronze industries were estimated to have consumed about 274,000 tons of zinc, of which about one-half was refined zinc metal and one-half was contained in brass and bronze scrap metal. According to CDA data, brass mills accounted for 85% of the total zinc consumed as metal and scrap in making copper-base alloys.

The zinc content in typical U.S.-manufactured automobiles was estimated to average about 40 pounds in 1991, the same as that in 1990. Diecastings accounted for about 19 pounds; corrosion protection via galvanizing and coatings, 18 pounds; and other, including rubber, brass, and zinc solder, 3 pounds.

The apparent domestic consumption of zinc oxide was about 150,000 tons, down from 165,000 tons in 1990 and 176,000 tons in 1989. Domestic production, exports and imports, also declined. Despite declining consumption, U.S. producers have increased their share of the U.S. zinc oxide market over the past 3 years, mainly at the expense of imports. Zinc oxide imports in 1991 were the lowest since 1984 and were about the same as those of 1988. Because the U.S. Bureau of Mines information on zinc oxide consumption by industry sector reflects only shipments as reported by the domestic producers, the consumption data listed in table 22 accounts for about 80% of the apparent market. Of the reported amounts, the rubber and chemical industries continued to be the principal consumers.

Stocks

Metal stocks held by domestic producers, consumers, and merchants continued to decline in 1991 and were at their lowest levels since the early years of World War II. In recent years, stock levels have tended to be in the 4- to 6-week consumption range, reflecting the general trend by consumers and merchants for lower inventories and just-in-time delivery. Metal stocks in the market economy countries (MEC), according to the International Lead and Zinc Study Group (ILZSG), were 657,000 tons at the end of 1991, up 107,000 tons from those at the end of 1990. Virtually all of the additional stocks were placed in LME warehouses; MEC industrial stocks tended to remain at 1990 levels.

Inventories of zinc in concentrate at domestic primary smelters totaled 29,000 tons at yearend compared with 35,500 tons at the end of 1990, according to the

American Bureau of Metal Statistics Inc. Concentrate stocks were at their lowest level in November.

Markets and Prices

All U.S. zinc producers switched to an LME price-basis in 1991. For zinc metal, they charged a premium, typically 3 to 5 cents per pound, over the LME price to cover importing costs—mainly tariffs, shipping, and insurance. At midyear, in efforts to maintain market share, domestic producers were forced on occasion to reduce their premiums on metal to less than 1 cent per pound.

Metals Week (MW) developed a new U.S. zinc price series to replace the producers' price series that ceased at yearend 1990. The new MW price, based on the daily LME spot price for SHG plus a premium that reflects market conditions, was used for the 1991 zinc price data in this report.

The LME established for the first time warehouses in the United States where LME registered metal could be picked up or delivered. The first such facility opened in February in Baltimore, MD. The LME planned to have additional warehouses in Chicago, IL; Long Beach, CA; Louisville, KY; New Haven, CT; and Toledo, OH, in operation by early 1992.

Zinc prices trended downward through June, continuing the general downtrend that began in July 1990. The Gulf War tended to halt the decline in the first third of the year but prices fell thereafter because of excessive world metal stocks, in part due to increased exports from Eastern European and socialist (EES) countries. Also exacerbating the price decline was the buildup of zinc concentrate stocks owing to large shipments of concentrate from arctic mines beginning in June. Prices were at their lowest levels in the summer months in the United States owing to continuing weak domestic and world demand and to reduced price premiums. Zinc prices rose in the last few months of the year to near the yearly high of January. This occurred despite the fact that there was little or no change in the underlying

market fundamentals. LME zinc stocks were at record levels, world demand was sluggish, and the market was generally oversupplied. Although several production cutbacks were anticipated, most analysts attributed the rise to speculative trading and short coverings at the LME.

Foreign Trade

The value of U.S. exports of basic zinc materials, including waste and scrap, was about \$375 million, up slightly from that of 1990 despite generally lower zinc prices in 1991. Exports of zinc concentrates accounted for 60% of the export value; scrap and zinc chemicals accounted for most of the remainder.

Exports of zinc in concentrates were the highest ever in 1991 and exceeded 1990's record high by 73%. Exports of zinc waste and scrap fell 12% in tonnage terms and 28% in value from those of 1990, but, nonetheless, these exports were the fourth highest in tonnage and value, historically.

General imports of zinc concentrate relative to imports for consumption continued to be high. The large disparity was due almost entirely to shipments of Canadian concentrate through Skagway, AK, to world markets. Imports of slab zinc and zinc oxide both fell, reflecting the general decline in domestic zinc consumption. The value of basic zinc imports was about \$785 million, down 28% from that of 1990.

World Review

Despite a general slowdown in the world economy, the world zinc industry continued at more or less the same level in 1991 as that in the previous year. Mine production was the second highest on record, whereas metal production exceeded 7 million tons for the fifth straight year and was the third highest ever recorded. However, zinc metal consumption, according to ILZSG, was less than 7 million tons in 1991. The imbalance between supply and consumption resulted in generally lower

zinc prices and increased world stock levels.

Higher mine output in Australia, Bolivia, China, Iran, Ireland, and Peru offset substantially lower output in Canada, Greenland, Mexico, Poland, the U.S.S.R., and Yugoslavia. Greenland became a nonproducer when its Black Angel Mine closed in 1990. World metal production followed the same general trend as mine production. Record-high production in the MEC exceeded production declines in the EES countries resulting in slightly higher world output than in 1990.

According to ILZSG, the MEC's consumed a record high 5.34 million tons of zinc metal compared with 5.25 million tons in 1990 and 5.20 million tons in 1989. The EES countries, on the other hand, were estimated in 1991 to have consumed only 1.63 million tons, 110,000 tons, and 28,000 tons less than those in 1990 and 1989, respectively. In 1991, the MEC accounted for slightly more than three-fourths of consumption and the EES countries slightly less than one-fourth. The world's leading consuming nations, in order of estimated consumption, were the United States, the U.S.S.R., Japan, and the Federal Republic of Germany. The United States, Japan, and Western Europe accounted for one-half of world consumption and about 70% of the MEC total. Based on ILZSG data, the principal uses of zinc metal in 1991 in the major MEC's were estimated to be as follows: galvanizing, 48%; brass and bronze, 19%; zinc-base alloys, 14%; chemicals, 8%; zinc semimanufactures, 7%; and other, 4%.

On a geographic basis, the Americas accounted for about 41% of world mine output. Europe, including the U.S.S.R., accounted for 24%; and Asia and Australia accounted for 17% and 15%, respectively. Despite 4 straight years of declining output, Canada remained the world's largest producer. Canada, together with Australia, China, Peru, the U.S.S.R., and the United States, accounted for 64% of the world's zinc mine production; 43 other countries accounted for the remaining 36%.

World exports of zinc concentrates totaled about 3.1 million tons, of which an estimated 90% was from the MEC. Australia, Canada, Peru, and the United States accounted for 75% of the MEC concentrate exports. Canada, Japan, the Republic of Korea, and the Western European countries were the largest importers.

World refined metal production was up about 30,000 tons over that of 1990. The U.S.S.R., the world's largest producer of zinc metal, was estimated to have produced 800,000 tons in 1991, about 11% less than that in the previous year. However, production declines in the U.S.S.R. and other countries were more than made up by small production increases in a number of countries, primarily Australia, Canada, China, France, Japan, Peru, Spain, and the United States. The MEC's and EES countries, respectively, accounted for 75% and 25% of world metal production. The largest producers—Canada, China, Japan, and the U.S.S.R.—accounted for 38% of world output in 1991; 33 other countries accounted for the remaining 62% of metal production.

World zinc mine capacity, based on the capacities of operating mines and temporarily closed mines expected to reopen, was about 8.39 million tons at the end of 1991, up about 45,000 tons from 1 year earlier. Twenty-nine mines closed in 1991, 10 mines opened, and 4 mines increased capacity. The Rampura-Agucha Mine in India, the Hajar Mine in Morocco, and the Sa Dena Hes Mine in Canada, each with zinc production capacities exceeding 50,000 tons, were the largest new mines to open. The Rubiales Mine in Spain (44,000-ton-per-year capacity) and the Lyon Lake Mine in Canada (30,000-ton-per-year capacity) were the largest in capacity terms to close permanently in 1991. Pasminco Ltd. permanently reduced the zinc capacity at its Elura Mine in Australia by two-thirds or by 57,000 tons owing to high costs.

World smelter capacity totaled about 8.36 million tons at yearend, up slightly more than 10,000 tons from that of 1990. One new greenfield smelter opened in India and four other smelters were being

expanded. The largest capacity expansion was a 100,000-ton-per-year increase at the Aviles smelter in Spain; the others planned capacity increases in the 10,000- to 25,000-ton range. Primary smelters in Austria, Germany, and Spain closed in 1991; the largest in capacity, 28,000 tons, was the Austrian smelter at Gailitz. According to ILZSG, an additional 458,000 tons of smelter capacity was scheduled to come on-stream by 1996. Greenfield smelters were under construction in China, India, Iran, Japan, and Thailand.

OUTLOOK

U.S. demand for zinc is forecast to rise slowly, increasing from slightly more than 0.93 million tons in 1991 to about 1.2 million tons by the year 2000. No major shifts in domestic zinc use are foreseen, although some present uses may yield further to substitution.

Although the United States has an adequate zinc resource base, imports are expected to continue to account for more than one-half of U.S. zinc supply in the next decade. Mine output is anticipated to approach historic high levels in the 1990's, but smelter capacity is expected to rise only modestly. No new primary zinc smelters are likely to be built in the United States during the 1990's owing to permitting delays and economic indecision caused by the uncertainty of environmental regulations and the long-term liability threat posed by Superfund legislation. Ironically, the United States is expected to be a major world exporter of zinc concentrates, and, at the same time, to remain the world's largest importer of refined zinc metal.

Secondary zinc recovery from waste and scrap is anticipated to be a strong growth sector for the zinc industry. Domestic secondary zinc production could increase substantially in the next decade and constitute the source of 40% of total U.S. zinc metal and compounds consumed annually by the year 2000. Increased secondary recovery is expected to be driven by public policies related to waste and scrap recycling, environment, and public health.

World zinc metal consumption is expected to continue upward, rising to about 8.5 million tons by the year 2000 from the 7 million tons consumed in 1991. No new major uses for zinc are expected. Traditional zinc uses, in meeting the needs of a rapidly growing and more affluent world population, are expected to be the driving force for increased zinc consumption in the next decade. However, growth is likely to be less in the early years of the decade because of monetary and restructuring problems associated with former EES nations.

World zinc resources and reserves are adequate to supply the increased demands of the 1990's. However, expected cumulative zinc mine output for the 1992-2000 period, about 73 million tons, will result in the extraction of about one-half of the 144 million tons of estimated 1991 world zinc ore reserves. (See table 41.)

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Zincscan.

TABLE 1
SALIENT ZINC STATISTICS

(Metric tons unless otherwise specified)

	1987	1988	1989	1990	1991	
United States:						
Production:						
Domestic ores, recoverable content	216,327	244,314	275,883	515,355	517,804	
Value	thousands \$199,924	\$324,249	\$499,103	\$847,485	\$602,426	
Slab zinc:						
From domestic ores	205,275	196,476	229,870	230,470	217,691	
From foreign ores	56,070	44,818	30,435	32,234	35,585	
From scrap	82,589	88,492	97,904	95,708	124,078	
Total	343,934	329,786	358,209	358,412	377,354	
Secondary zinc ¹	269,319	248,461	249,122	245,692	229,621	
Exports:						
Ores and concentrates (zinc content)	16,921	33,590	78,877	220,446	381,416	
Slab zinc	1,082	482	5,532	1,238	1,253	
Imports for consumption:						
Ores and concentrates (zinc content)	46,464	62,966	40,974	46,684	45,419	
Slab zinc	705,985	749,133	711,554	631,742	549,137	
Stocks of slab zinc, Dec. 31:						
Industry (rounded)	96,400	85,900	90,500	87,400	79,300	
Government stockpile	340,577	340,577	340,577	340,577	340,577	
Consumption:						
Slab zinc:						
Reported	798,148	833,473	884,655	801,969	764,038	
Apparent (rounded) ²	1,052,000	1,089,000	1,060,000	992,000	933,000	
All classes (rounded) ³	1,324,000	1,340,000	1,311,000	1,240,000	1,165,000	
Price: High-Grade, cents per pound (delivered)	41.92	60.20	82.02	74.59	52.77	
World:						
Production:						
Mine	thousand metric tons	7,188	6,980	7,100	7,320	7,282
Smelter	do.	7,022	7,163	7,177	7,053	7,082
Price: London, cents per pound		36.20	51.11	77.64	66.46	50.67

¹Estimated. ²Revised.

¹Excludes secondary slab and remelt zinc.

²Domestic production plus net imports plus or minus stock changes.

³Based on apparent consumption of slab zinc plus zinc content of ores and concentrates and secondary materials.

**TABLE 2
MINE PRODUCTION OF
RECOVERABLE ZINC
IN THE UNITED STATES, BY
MONTH**

(Metric tons)		
Month	1990	1991
January	39,042	45,927
February	36,880	42,298
March	38,542	44,203
April	38,323	45,882
May	40,064	49,860
June	39,222	37,195
July	51,462	43,399
August	57,934	47,799
September	45,335	49,911
October	43,252	39,312
November	41,001	33,677
December	44,298	38,341
Total	515,355	517,804

**TABLE 3
MINE PRODUCTION OF RECOVERABLE ZINC IN THE UNITED
STATES, BY STATE**

(Metric tons)					
State	1987	1988	1989	1990	1991
Alaska	—	—	W	W	W
Colorado	W	W	W	W	W
Idaho	W	W	W	W	W
Illinois	W	W	W	W	W
Kentucky	10	W	—	W	—
Missouri	34,956	41,322	50,790	48,864	42,506
Montana	W	18,935	W	W	W
Nevada	—	—	—	7,889	W
New Mexico	—	—	W	W	W
New York	W	W	W	W	W
Oregon	—	—	—	—	751
Tennessee	115,699	119,954	W	W	W
Washington	—	—	—	—	W
Total	216,327	244,314	275,883	515,355	517,804

W Withheld to avoid disclosing company proprietary data; included in "Total."

**TABLE 4
LEADING ZINC-PRODUCING MINES IN THE UNITED STATES IN 1991, IN ORDER OF OUTPUT**

Rank	Mine	County and State	Operator	Source of zinc
1	Red Dog	Northwest Arctic, AK	Cominco Alaska Inc.	Zinc ore.
2	Elmwood-Gordonsville	Smith, TN	Jersey Miniere Zinc Co.	Do.
3	Greens Creek	Admiralty Island, AK	Greens Creek Mining Co.	Do.
5	Pierrepont	St. Lawrence, NY	Zinc Corp. of America	Do.
4	Balmat	do.	do.	Do.
6	Young	Jefferson, TN	ASARCO Incorporated	Do.
7	Montana Tunnels	Jefferson, MT	Montana Tunnels Mining Inc.	Do.
8	Immel	Knox, TN	ASARCO Incorporated	Do.
9	New Market	Jefferson, TN	do.	Do.
10	Jefferson City	do.	Union Zinc Co.	Do.
11	Buick	Iron, MO	The Doe Run Co.	Lead-zinc ore.
12	Leadville Unit	Lake, CO	ASARCO Incorporated	Zinc ore.
13	West Fork	Reynolds, MO	do.	Lead-zinc ore.
14	Magmont	Iron, MO	Cominco American Inc.	Do.
15	Coy	Jefferson, TN	ASARCO Incorporated	Zinc ore.
16	Fletcher	Reynolds, MO	The Doe Run Co.	Lead-zinc ore.
17	Rosiclare	Hardin and Pope, IL	Ozark-Mahoning Co.	Fluorspar.
18	Ward/Taylor	White Pine, NV	Alta Gold Co.	Lead-zinc ore.
19	Sunnyside	San Juan, CO	San Juan County Mining Venture	Do.
20	Van Stone	Stevens, WA	Equinox Resources	Zinc ore.
21	Pinos Altos	Grant, NM	Cyprus Sierrita Corp.	Copper ore.
22	Sweetwater	Reynolds, MO	ASARCO Incorporated	Lead-zinc ore.
23	Viburnum No. 29	Iron, MO	The Doe Run Co.	Do.
24	Lucky Friday	Shoshone, ID	Hecla Mining Co.	Do.
25	Casteel ¹	Iron, MO	The Doe Run Co.	Copper-lead ore.

¹Includes Brushy Creek Mill.

**TABLE 5
PRODUCTION OF ZINC AND LEAD IN THE UNITED STATES IN 1991, BY STATE AND
CLASS OF ORE, FROM OLD TAILINGS, ETC., IN TERMS OF RECOVERABLE METALS**

(Metric tons)

State	Zinc ore			Lead ore			Zinc-lead ore		
	Gross weight (dry basis)	Zinc	Lead	Gross weight (dry basis)	Zinc	Lead	Gross weight (dry basis)	Zinc	Lead
Alaska	W	W	W	—	—	—	—	—	—
Arizona	—	—	—	—	—	—	—	—	—
Colorado	—	—	—	—	—	—	W	W	W
Idaho	W	W	W	—	—	—	W	W	W
Illinois	—	—	—	—	—	—	—	—	—
Missouri	—	—	—	—	—	—	5,666,404	41,668	319,219
Montana	W	W	W	—	—	—	W	W	W
Nevada	—	—	—	—	—	—	W	W	W
New Mexico	—	—	—	—	—	—	—	—	—
New York	W	W	W	—	—	—	—	—	—
Oregon	—	—	—	—	—	—	—	—	—
Tennessee	W	W	W	—	—	—	—	—	—
Washington	W	W	W	—	—	—	—	—	—
Total	10,941,367	456,535	82,856	—	—	—	W	W	W
Percent of total zinc or lead	XX	84	16	XX	—	—	XX	W	W
	Copper-zinc, copper-lead, copper-zinc-lead ores			All other sources ^{1 2}			Total ³		
	Gross weight (dry basis)	Zinc	Lead	Gross weight (dry basis)	Zinc	Lead	Gross weight (dry basis)	Zinc	Lead
Alaska	—	—	—	—	—	—	W	W	W
Arizona	—	—	—	W	—	W	W	—	W
Colorado	—	—	—	—	—	—	W	W	W
Idaho	—	—	—	W	—	W	W	W	W
Illinois	—	—	—	—	W	—	—	W	—
Missouri	4737,428	4839	432,775	—	—	—	6,403,832	42,506	351,995
Montana	—	—	—	2,807,435	—	397	W	W	W
Nevada	—	—	—	W	W	W	W	W	W
New Mexico	—	—	—	W	W	193	W	W	193
New York	—	—	—	—	—	—	W	W	W
Oregon	18,767	751	—	—	—	—	18,767	751	—
Tennessee	—	—	—	—	—	—	W	W	W
Washington	—	—	—	—	—	—	W	W	W
Total	756,195	1,590	32,775	W	W	W	30,013,757	517,804	465,931
Percent of total zinc or lead	XX	—	7	XX	W	W	XX	100	100

W Withheld to avoid disclosing company proprietary data; included in "Total." XX Not applicable.

¹Includes zinc and lead recovered from copper, gold, gold-silver, and silver ores, from fluor spar and from mill tailings.

²Excludes tonnages of fluor spar in Illinois from which zinc and lead were recovered as byproducts.

³Data may not add to totals shown because of independent rounding.

⁴Includes Brushy Creek Mill.

TABLE 6
PRIMARY AND SECONDARY SLAB ZINC PRODUCED IN THE UNITED STATES

(Metric tons)

	1987	1988	1989	1990	1991
Primary:					
From domestic ores	205,275	196,476	229,870	230,470	217,691
From foreign ores	56,070	44,818	30,435	32,234	35,585
Total	261,345	241,294	260,305	262,704	253,276
Secondary:					
At primary smelters	W	W	W	W	W
At secondary smelters	W	W	W	W	W
Total	82,589	88,492	97,904	95,708	124,078
Grand total (excludes zinc recovered by remelting)	343,934	329,786	358,209	358,412	377,354

Revised. W Withheld to avoid disclosing company proprietary data.

TABLE 7
DISTILLED AND ELECTROLYTIC ZINC, PRIMARY AND SECONDARY, PRODUCED IN THE UNITED STATES, BY GRADE

(Metric tons)

Grade	1987	1988	1989	1990	1991
Special High	85,010	90,034	113,819	116,647	110,187
High	88,952	74,870	79,145	86,006	96,469
Continuous Galvanizing	38,751	44,890	48,252	50,577	42,556
Controlled Lead	W	W	W	W	W
Prime Western	131,221	119,992	116,993	105,182	128,142
Total	343,934	329,786	358,209	358,412	377,354

W Withheld to avoid disclosing company proprietary data, included in "Prime Western."

TABLE 8
SLAB ZINC CAPACITY OF PRIMARY ZINC PLANTS IN THE UNITED STATES, BY TYPE OF PLANT AND COMPANY

Type of plant and company	Slab zinc capacity (metric tons)	
	1990	1991
Electrolytic:		
Big River Zinc Corp., Sauget, IL	82,000	82,000
Jersey Miniere Zinc Co., Clarksville, TN	98,000	98,000
Zinc Corp. of America, Bartlesville, OK	51,000	54,000
Electrothermic:		
Zinc Corp. of America, Monaca, PA ¹	123,000	136,000
Total available capacity	354,000	370,000
Total operating capacity	354,000	370,000

¹Includes secondary capacity.

TABLE 9
SECONDARY ZINC PLANT CAPACITY IN THE UNITED STATES, BY
COMPANY

Company	Plant location	Capacity (metric tons)	
		1990	1991
Arco Alloys Corp.	Detroit, MI		
W.J. Bullock Inc.	Fairfield, AL		
T.L. Diamond & Co. Inc.	Spelter, WV		
Florida Steel Co.	Jackson, TN		
Gulf Reduction Corp.	Houston, TX		
Hugo Neu-Proler Co.	Terminal Island, CA		
Huron Valley Steel Corp.	Belleville, MI	58,000	58,000
Indiana Steel & Wire Co. Inc.	Muncie, IN		
Interamerican Zinc Inc.	Adrian, MI		
New England Smelting Works, Inc.	West Springfield, MA ¹		
Nucor Yamato Steel Co.	Blytheville, AR		
The River Smelting & RFG Co.	Cleveland, OH		
Zinc Corp. of America	Palmerton, PA		

¹Closed in 1990.

TABLE 10
U.S. PROCESSORS OF STEELMAKING ELECTRIC ARC FURNACE DUSTS AND CAPACITIES

(Metric tons)

Company	Location	Process	Date of startup	Annual EAF capacity	Potential zinc recovery
Florida Steel Co.	Jackson, TN	Plasma	1989	7,200	1,400
Horsehead Development Resource Co., Inc.	Calumet City, IL	Waelz	1988	72,000	—
Do.	Monaca, PA ¹	Flame reactor	1990	18,000	—
Do.	Palmerton, PA	Waelz	1981	245,000	75,000
Do.	Rockwood, TN	do.	1990	90,000	—
Laclede Steel Co.	St. Louis, MO	Elkem	1992	36,000	6,000
North Star Steel Corp.	Beaumont, TX	Flame reactor	1992	27,000	5,000
Nucor-Yamamoto Steel Co.	Blytheville, AR	Plasma	1989	11,000	1,800
Zia Technology of Texas Inc.	Caldwell, TX	Inclined rotary	1992	27,000	4,500
				533,200	93,700

¹Inactive.

TABLE 11
STOCKS AND CONSUMPTION OF NEW AND OLD ZINC SCRAP IN THE UNITED STATES IN 1991, BY TYPE OF SCRAP

(Metric tons, zinc content)

Type of scrap	Stocks, Jan. 1	Receipts	Consumption			Stocks, Dec. 31
			New scrap	Old scrap	Total	
Diecastings	256	4,321	—	4,345	4,345	232
Flue dust	W	7,804	4,298	4,292	8,590	W
Fragmentized diecastings	W	27,836	—	27,856	27,856	W
Galvanizer's dross	1,969	83,334	83,439	—	83,439	1,864
Old zinc ¹	90	1,341	—	1,372	1,372	59
Remelt die-cast slab	W	W	—	W	W	W
Remelt zinc ²	W	184	183	—	183	W
Skimmings and ashes ³	4,539	31,857	31,664	—	31,664	4,732
Steelmaking dust	—	44,573	22,287	22,286	44,573	—
Other ⁴	6,028	18,729	4,183	15,030	19,213	4,739
Total	12,882	219,979	146,054	75,181	221,235	11,626

W Withheld to avoid disclosing company proprietary data; included in "Other."

¹Includes engraver's plates and rod and die scrap.

²Includes new clippings.

³Includes sal skimmings and die-cast skimmings.

⁴Includes chemical residues and solutions and electrogalvanizing anodes.

TABLE 13
ZINC RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1990		1991	
	KIND OF SCRAP			
New scrap:				
Zinc-base	97,914	118,232		
Copper-base	134,360	114,894		
Magnesium-base	181	181		
Total	232,455	233,307		
Old scrap:				
Zinc-base	86,607	95,206		
Copper-base	21,632	24,320		
Aluminum-base	512	661		
Magnesium-base	194	205		
Total	108,945	120,392		
Grand total	341,400	353,699		

FORM OF RECOVERY

Metal:		
Slab zinc	95,708	124,078
Zinc dust	24,105	22,750
Other ¹	11,804	8,595
Total	131,617	155,423
In zinc-base alloys	5,144	4,979
In brass and bronze	148,247	127,009
In other metal alloys	257	W
In chemical products:		
Zinc oxide (lead free)	34,726	34,394
Zinc sulfate	12,769	23,385
Zinc chloride	7,436	5,311
Miscellaneous	1,204	3,198
Total	209,783	198,276
Grand total	341,400	353,699

¹Revised. W Withheld to avoid disclosing company proprietary data; included in "Miscellaneous."

²Includes electrogalvanizing anodes and zinc content of slab made from remelt die-cast slab.

TABLE 12
PRODUCTION OF ZINC PRODUCTS FROM ZINC-BASE SCRAP IN THE UNITED STATES

(Metric tons)

Product	1987	1988	1989	1990	1991
Electrogalvanizing anodes	—	—	W	W	W
Redistilled slab zinc	82,589	88,492	97,90	95,708	124,078
Remelt die-cast slab	825	907	4,167	5,144	4,979
Other metal alloys	163	317	272	257	W
Other zinc metal products	6,741	8,016	5,564	1,804	9,137
Secondary zinc in chemical products	79,361	55,972	57,576	56,135	65,746
Zinc dust	28,620	24,205	24,909	24,105	22,750

¹Revised. W Withheld to avoid disclosing company proprietary data; included in "Other zinc metal products."

TABLE 14
U.S. CONSUMPTION OF ZINC

(Metric tons)

	1987	1988	1989	1990	1991
Slab zinc, apparent (rounded)	1,052,000	1,089,000	1,060,000	*992,000	933,000
Ores and concentrates (zinc content)	2,536	2,412	2,107	2,178	2,098
Secondary (zinc content) ¹	269,319	248,461	249,122	*245,692	229,621
Total (rounded)	1,324,000	1,340,000	1,311,000	*1,240,000	1,165,000

*Revised.

¹Excludes secondary slab and remelt zinc.

TABLE 15
ESTIMATED¹ APPARENT
CONSUMPTION OF SLAB ZINC,
ACCORDING TO INDUSTRY USE
AND PRODUCT

(Metric tons)

Industry use and product	1990	1991
Galvanizing:		
Sheet and strip	*381,400	343,900
Other	*124,500	120,700
Total	*505,900	464,600
Brass and bronze	*141,700	133,000
Zinc-base alloys	*205,000	199,700
Zinc oxide	*68,100	65,000
Other uses ²	*71,300	70,700
Estimated apparent consumption	*992,000	933,000

*Revised.

¹Based on reported slab zinc consumption.

²Includes zinc used in making zinc dust, wet batteries, desilverizing lead, powder, alloys, anodes, chemicals, castings, light metal alloys, rolled zinc, and miscellaneous uses not elsewhere specified.

TABLE 16
U.S. REPORTED CONSUMPTION
OF SLAB ZINC,
BY INDUSTRY USE AND
PRODUCT

(Metric tons)

Industry use and product	1990	1991
Galvanizing:		
Sheet and strip	*295,693	272,788
Other	*92,728	91,841
Total	*388,421	364,629
Brass and bronze	*104,276	97,952
Zinc-base alloy	171,771	169,883
Zinc oxide	67,532	64,035
Other uses ¹	*69,969	67,539
Grand total	*801,969	764,038

*Revised.

¹Includes zinc used in making zinc dust, wet batteries, desilverizing lead, powder, alloys, anodes, chemicals, castings, light metal alloys, rolled zinc, and miscellaneous uses not elsewhere specified.

TABLE 17
U.S. REPORTED CONSUMPTION OF SLAB ZINC IN 1991, BY INDUSTRY
USE AND GRADE

(Metric tons)

Industry use	Special High Grade	High-Grade	Prime Western	Remelt and other grades	Total ¹
Galvanizing	84,616	69,429	155,393	55,191	364,629
Zinc-base alloys	167,764	W	—	W	169,883
Brass and bronze	45,732	19,824	W	W	97,952
Zinc oxide	W	W	W	—	64,035
Other	W	W	W	W	67,539
Total ¹	421,316	91,468	189,930	57,786	764,038

W Withheld to avoid disclosing company proprietary data; included in "Total."

¹Data may not add to totals shown because of withheld figures.

TABLE 18
U.S. REPORTED CONSUMPTION OF SLAB ZINC IN 1991, BY STATE¹

(Metric tons)

State	Galva- nizers	Brass mills ²	Die- casters ³	Other ⁴	Total
Alabama	W	W	—	—	9,779
California	16,955	W	—	W	18,371
Connecticut	W	1,725	W	W	10,614
Florida	5,458	—	—	—	5,458
Illinois	55,179	W	28,205	W	116,361
Indiana	30,595	W	W	W	35,652
Michigan	W	W	36,589	W	66,744
Nebraska	W	—	—	W	9,240
New York	2,778	W	63,420	W	94,463
Ohio	44,288	W	W	W	75,481
Pennsylvania	W	W	W	W	181,607
Tennessee	W	—	—	W	43,740
Texas	W	—	—	W	13,405
Undistributed	209,290	96,153	41,602	131,572	82,894
Total	364,543	97,878	169,816	131,572	763,809

W Withheld to avoid disclosing company proprietary data; included with "Total" and "Undistributed."

¹Excludes remelt zinc.

²Includes brass mills, brass ingotmakers, and brass foundries.

³Includes producers of zinc-base alloys for diecastings, stamping dies, and rods.

⁴Includes slab zinc used in rolled zinc products and in zinc oxide.

TABLE 19
**ROLLED ZINC PRODUCED AND
 QUANTITY AVAILABLE FOR
 CONSUMPTION
 IN THE UNITED STATES**

(Metric tons)

	1990	1991
Production ¹	47,882	41,756
Exports	11,881	10,385
Imports for consumption	929	537
Available for consumption	38,875	30,503

¹Includes other plate more than 0.375 inch thick and rod and wire.

TABLE 20
ZINC CONTENT OF PRODUCTION AND SHIPMENTS OF ZINC
PIGMENTS AND COMPOUNDS¹ IN THE UNITED STATES

(Metric tons)

	1990		1991	
	Production	Shipments	Production	Shipments
Zinc chloride ²	7,436	6,530	5,311	5,554
Zinc oxide	98,047	98,987	94,564	96,064
Zinc sulfate	14,947	14,115	25,483	24,873

¹Excludes leaded zinc oxide and lithopone.

²Includes zinc content of zinc ammonium chloride.

TABLE 21
ZINC CONTENT OF ZINC PIGMENTS AND COMPOUNDS¹ PRODUCED BY DOMESTIC MANUFACTURERS,
BY SOURCE

(Metric tons)

	1990				1991			
	Zinc in pigments and compounds produced from			Total	Zinc in pigments and compounds produced from			Total
	Ore	Slab zinc	Secondary material		Ore	Slab zinc	Secondary material	
Zinc chloride ²	—	—	7,436	7,436	—	—	5,311	5,311
Zinc oxide	—	63,321	34,726	98,047	—	60,170	34,394	94,564
Zinc sulfate	W	—	14,947	14,947	W	—	25,483	25,483

W Withheld to avoid disclosing company proprietary data; included with "Secondary material."

¹Excludes leaded zinc oxide and lithopone.

²Includes zinc content of zinc ammonium chloride.

TABLE 22
REPORTED DISTRIBUTION OF ZINC CONTAINED IN ZINC OXIDE
SHIPMENTS, BY INDUSTRY¹

(Metric tons)

Industry	1987	1988	1989	1990	1991
Agriculture	3,477	1,988	1,520	1,764	1,822
Ceramics	4,901	3,302	2,780	2,618	2,973
Chemicals	22,789	21,898	22,462	20,723	20,177
Paints	8,007	3,441	4,695	4,579	3,848
Photocopying	W	W	W	W	W
Rubber	63,589	55,213	57,781	56,622	55,254
Other	7,814	12,189	13,277	12,681	11,990
Total	110,577	98,031	102,515	98,987	96,064

W Withheld to avoid disclosing company proprietary data; included in "Other."

¹In addition, zinc oxide was imported as follows, in metric tons: 1987--57,276; 1988--73,042; 1989--59,557; 1990--49,454; and 1991--38,215; distribution cannot be distinguished by industry.

**TABLE 23
DISTRIBUTION OF ZINC CONTAINED IN SULFATE SHIPMENTS**

(Metric tons)

Industry	1987	1988	1989	1990	1991
Agriculture	14,934	13,602	10,922	12,337	16,152
Other	3,096	2,599	2,749	1,778	8,721
Total	18,030	16,201	13,671	14,115	24,873

**TABLE 24
U.S. PRODUCERS OF ZINC OXIDE AND CAPACITY, BY COMPANY**

Company	Plant location	Capacity (metric tons)	
		1990	1991
ASARCO Incorporated	Hillsboro, IL		
Big River Zinc Corp.	Sauget, IL		
Eagle Zinc Co.	Hillsboro, IL		
Interamerican Zinc Inc.	Adrian, MI		
Midwest Zinc Corp.	Chicago, IL	165,000	156,000
North American Oxide Inc.	Clarksville TN		
Pasco Zinc Products Corp. ¹	Memphis, TN		
Zinc Corp. of America	Monaca, PA		
Do.	Palmerton, PA		

¹Closed in July 1991.

**TABLE 25
U.S. PRODUCERS OF ZINC SULFATE AND CHLORIDE
PRODUCTS IN 1991**

Company	Plant location	Sulfate production	Chloride production
American Microtrace	Fairbury, NE	X	—
B & W Micronutrients	Bartlesville, OK	X	—
Bay Zinc Co.	Moxee City, WA	X	—
Big River Zinc Corp.	Sauget, IL	X	—
The Chemical & Pigment Co.	Pittsburg, CA	X	X
Cozinco Inc.	Denver, CO	X	—
Frit Industries Inc.	Ozark, AL	X	—
Liquid Chemical Corp.	Hanford, CA	X	—
Madison Industries Inc.	Old Bridge, NJ	X	X
Mineral Research & Development Corp.	Freeport, TX	—	X
Zaclon Inc.	Cleveland, OH	—	X
Zinc Corp. of America	Monaca, PA	X	—

X Denotes producer of product

TABLE 26
ESTIMATED STOCKS OF SLAB ZINC IN THE UNITED STATES,
DECEMBER 31¹

(Metric tons)

	1987	1988	1989	1990	1991
Primary producers	13,400	6,000	7,200	6,000	6,000
Secondary producers	3,200	700	1,000	600	1,300
Consumers	57,400	64,900	60,100	60,400	56,300
Merchants	22,400	14,300	22,200	20,400	15,700
Total	96,400	85,900	90,500	87,400	79,300

¹Revised.

²Rounded to the nearest hundred.

TABLE 27
AVERAGE MONTHLY U.S., LME,¹ AND EUROPEAN PRODUCER
PRICES FOR EQUIVALENT ZINC

(Metallic zinc, cents per pound)

Month	1990			1991	
	United States ²	LME cash	European producer ³	United States ⁴	LME cash
January	67.63	58.66	58.43	58.08	54.71
February	64.75	63.28	63.02	55.93	53.89
March	73.78	75.57	73.22	56.11	54.37
April	80.74	76.46	74.72	57.63	56.89
May	85.60	80.50	78.76	49.84	49.48
June	87.19	77.78	76.24	48.40	48.15
July	86.10	74.25	73.02	48.67	48.22
August	78.98	73.26	71.41	48.36	47.46
September	77.77	69.74	67.99	49.78	46.41
October	67.54	61.35	61.22	48.56	44.98
November	62.94	57.96	57.69	54.64	49.59
December	62.09	57.40	57.13	57.29	53.89
Average	74.59	66.46	67.74	52.77	50.67

¹London Metal Exchange.

²Based on High-Grade zinc delivered.

³As of Jan. 1991 European Producer Price was discontinued.

⁴Metals Week averages for Special High Grade based on LME spot prices plus premiums depending on market conditions.

Source: Metals Week.

TABLE 28
U.S. PRODUCERS REPORTING ZINC DUST PRODUCTION IN 1991

Big River Zinc Corp.	Sauget, IL
Gulf Reduction Corp.	Houston, TX
Jersey Minere Zinc Co.	Clarksville, TN
Mineral Research & Development Corp.	Freeport, TX
Southern Zinc	Fulton, GA
T.L. Diamond & Co. Inc.	Spelter, WV
Zinc Corp. of America	Monaca, PA

TABLE 29
U.S. EXPORTS OF ZINC AND ZINC ALLOYS, BY COUNTRY

Country	1989		1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Unwrought zinc and zinc alloys:						
Belgium	—	—	145	\$103	—	—
Canada	2,023	\$5,275	4,338	7,973	4,524	\$6,283
Ecuador	—	—	—	—	18	30
Germany, Federal Republic of	4,787	7,187	500	872	47	190
Guatemala	—	—	—	—	80	82
Hong Kong	210	411	—	—	—	—
India	19	20	—	—	8	29
Israel	6	36	1	9	—	—
Jamaica	207	451	27	52	11	21
Japan	8	14	130	323	38	185
Korea, Republic of	10	36	156	470	—	—
Mexico	86	162	97	205	383	856
Netherlands	9	32	—	—	—	—
New Zealand	—	—	—	—	19	21
Panama	18	49	11	24	7	16
Singapore	—	—	2	15	—	—
Suriname	—	—	—	—	16	40
Taiwan	454	455	181	295	297	810
United Kingdom	(¹)	3	—	—	6	35
Other ²	118	302	216	963	23	82
Total	7,955	14,433	5,804	11,304	5,477	\$8,679
Wrought zinc and zinc alloys:						
Australia	34	86	339	662	274	487
Austria	—	—	34	261	235	1,346
Bahamas	4	7	15	51	8	20
Belgium	—	—	37	73	57	114
Brazil	44	81	27	109	110	292
Canada	1,932	2,293	2,574	6,833	3,319	7,423
Chile	17	62	28	79	22	40
Colombia	19	61	10	54	8	202
Dominican Republic	131	307	15	27	19	17
Ecuador	10	38	38	98	7	17
France	96	66	99	31	121	43
Germany, Federal Republic of	1,218	466	2,081	632	3,280	825
Guyana	2	5	215	79	—	—
Hong Kong	192	138	4	37	25	41
India	3	23	321	212	179	116
Jamaica	1,691	1,820	58	101	6	8
Japan	50	223	55	188	63	320
Korea, Republic of	28	77	131	187	81	135
Mexico	488	1,312	633	1,254	3,269	6,216
Netherlands Antilles	3	10	7	23	1	10
Panama	20	37	7	21	5	12
Philippines	14	62	56	161	85	254
Saudi Arabia	12	33	7	19	9	18

See footnotes at end of table.

TABLE 29—Continued
U.S. EXPORTS OF ZINC AND ZINC ALLOYS, BY COUNTRY

Country	1989		1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Singapore	6	46	17	120	12	30
South Africa, Republic of	8	104	10	31	6	21
Spain	(¹)	2	(¹)	11	14	19
Sudan	127	241	—	—	—	—
Taiwan	12,548	9,697	7,900	5,444	4,629	2,879
United Kingdom	199	333	46	114	6	48
Venezuela	5	27	29	73	30	188
Other ⁴	267	791	819	1,556	656	1,325
Total	19,168	18,448	15,612	18,541	16,536	22,466

¹Revised.

²Less than 1/2 unit.

³Includes Algeria, Argentina, Bermuda, Brazil, Chile, China, Colombia, Denmark, Dominican Republic, Egypt, El Salvador, Greece, Guyana, Indonesia, Iraq, Jordan, Malaysia, Nigeria, Peru, Portugal, Saudi Arabia, the Republic of South Africa, Spain, Sweden, Syria, Tanzania, Thailand, Trinidad and Tobago, the United Arab Emirates, and Venezuela.

⁴Data do not add to total shown because of independent rounding.

⁵Includes Argentina, Aruba, Bangladesh, Bermuda, Cayman Islands, China, Costa Rica, Denmark, Egypt, El Salvador, Federated States of Micronesia, French Guiana, Greece, Guatemala, Guyana, Haiti, Honduras, Iceland, Indonesia, Ireland, Israel, Italy, Jordan, Lebanon, Leeward and Windward Islands, Malaysia, Martinique, Morocco, the Netherlands, New Zealand, Pakistan, Peru, Suriname, Sweden, Switzerland, Syria, Thailand, Trinidad and Tobago, Turkey, the United Arab Emirates, Uruguay, and Yugoslavia.

Source: Bureau of the Census.

TABLE 30
U.S. EXPORTS OF ZINC

Year	Blocks, pigs, anodes, etc.				Dust and flakes		Ores and concentrates	
	Unwrought		Unwrought alloys		Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)				
1989	5,532	\$8,783	2,423	\$5,650	8,137	\$13,861	78,877	\$64,224
1990	1,238	2,347	4,566	8,957	8,701	17,039	220,446	188,686
1991	1,253	1,999	4,224	6,681	5,737	8,247	381,416	221,948

Year	Wrought zinc and zinc alloys						Zinc oxide	
	Waste and scrap (zinc content)		Sheets, plates, strips		Angles, bars, pipes, rods, etc.		Quantity (metric tons)	Value (thousands)
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)		
1989	108,086	\$75,947	16,515	\$14,816	2,653	\$3,632	12,286	\$17,872
1990	109,316	85,749	11,881	9,893	3,731	8,648	7,141	10,032
1991	96,314	61,706	10,385	9,919	6,151	12,547	6,653	8,756

Source: Bureau of the Census.

TABLE 31
U.S. EXPORTS OF ZINC ORES AND CONCENTRATES,
BY COUNTRY

(Zinc content)

	1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	3,615	\$2,060	3,618	\$2,065
Belgium	61,393	39,058	108,147	54,188
Bulgaria	—	—	2,000	1,668
Canada	86,105	94,368	184,398	118,368
France	5,240	1,845	—	—
Germany, Federal Republic of	—	—	49	500
Haiti	—	—	15	195
Italy	12,567	12,024	14,982	6,975
Jamaica	—	—	7	19
Japan	42,928	30,247	42,991	23,942
Korea, Republic of	1,915	1,819	7,090	4,996
Mexico	254	211	1,068	1,107
Netherlands	—	—	81	48
Switzerland	—	—	(¹)	4
Taiwan	5	7	4	10
United Kingdom	6,424	7,047	16,966	7,863
Total	220,446	188,686	381,416	221,948

¹Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 32
U.S. EXPORTS OF ZINC COMPOUNDS

	1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Lithopone	370	\$541	1,176	\$1,984
Zinc chloride	2,267	2,275	1,306	905
Zinc compounds, n.s.p.f.	2,205	29,935	3,944	30,474
Zinc oxide	7,141	10,032	6,653	8,756
Zinc sulfate	3,200	6,180	3,087	8,475
Zinc sulfide	47	251	146	508

Source: Bureau of the Census.

TABLE 33
U.S. GENERAL IMPORTS OF ZINC, BY COUNTRY

Country	1989		1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
ORES AND CONCENTRATES (zinc content)						
Australia	600	\$78	316	\$41	—	—
Bolivia	28	6	5,055	3,061	4,451	\$1,961
Canada	183,122	72,346	209,081	41,287	*132,511	NA
Chile	15	10	—	—	—	—
Honduras	—	—	(¹)	(¹)	—	—
Italy	—	—	—	—	29	8
Japan	—	—	35	11	—	—
Mexico	16,408	9,114	*24,455	*7,753	16,268	4,563
Peru	5,301	3,036	1,843	245	17,357	7,129
Total ²	<u>205,474</u>	<u>84,590</u>	<u>240,785</u>	<u>52,398</u>	<u>170,616</u>	<u>³13,662</u>
BLOCKS, PIGS, OR SLABS⁴						
Argentina	3,013	4,490	2,312	3,611	600	597
Australia	42,766	69,473	44,510	69,658	19,684	21,346
Belgium	2,562	4,221	5,779	9,477	76	130
Brazil	8,899	15,158	19,211	31,384	13,750	15,708
Canada	435,254	730,463	372,458	590,460	390,871	451,598
China	317	524	2,283	3,482	—	—
Finland	24,321	41,386	17,085	27,769	13,996	14,385
France	8,110	13,789	2,179	3,280	—	—
Germany, Federal Republic of	3,512	5,884	2,340	3,968	1	27
Guinea	—	—	133	207	—	—
Hong Kong	150	252	1,193	1,981	17	20
Israel	—	—	—	—	20	19
Italy	—	—	6,000	9,659	—	—
Japan	(⁵)	2	(⁶)	3	39	35
Korea, Republic of	2,352	3,776	(⁶)	2	—	—
Mexico	70,817	115,330	72,330	109,916	56,743	58,447
Monaco	136	231	—	—	—	—
Netherlands	4,685	7,532	1,733	2,442	—	—
Norway	28,801	47,325	23,247	36,569	6,898	6,550
Peru	34,409	54,772	23,333	34,186	20,727	24,672
Poland	—	—	822	1,066	—	—
South Africa, Republic of	201	331	—	—	—	—
Spain	26,277	44,747	23,919	37,460	21,192	22,522
Sweden	8	137	—	—	—	—
Taiwan	220	426	200	325	5	12
United Kingdom	1,239	2,114	660	1,028	714	3,613
Yugoslavia	—	—	38	59	—	—
Zaire	13,155	20,720	9,975	13,569	2,636	2,748

See footnotes at end of table.

TABLE 33—Continued
U.S. GENERAL IMPORTS OF ZINC, BY COUNTRY

Country	1989		1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
BLOCKS, PIGS, OR SLABS⁴—Continued						
Zambia	749	1,159	—	—	—	—
Total²	711,953	1,184,244	631,742	991,562	547,972	622,429

¹Estimated. NA Not available.

²Revised to zero.

³Data may not add to totals shown because of independent rounding.

⁴Value data for Canada is not included in total.

⁵In addition, in 1991, 3,491 tons of zinc anodes was imported from Belgium, Canada, China, France, the Federal Republic of Germany, Hong Kong, India, Italy, Japan, Republic of Korea, Netherlands, Taiwan, and Thailand.

⁶Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 34
U.S. IMPORTS FOR CONSUMPTION OF ZINC, BY COUNTRY

Country	1989		1990		1991	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
ORES AND CONCENTRATES (zinc content)						
Bolivia	—	—	5,007	\$3,053	4,451	\$1,961
Canada	20,161	\$11,150	17,187	7,153	10,255	8,702
Italy	—	—	—	—	10	2
Japan	—	—	35	11	—	—
Mexico	16,408	9,114	24,455	7,753	16,268	4,563
Peru	4,405	2,783	—	—	14,435	6,881
Total ¹	40,974	23,047	46,684	17,970	45,419	22,110
BLOCKS, PIGS, OR SLABS²						
Argentina	3,013	4,491	2,312	3,611	600	597
Australia	42,766	69,473	44,510	69,658	19,684	21,346
Belgium	2,562	4,221	5,779	9,477	76	130
Brazil	8,899	15,158	19,211	31,384	13,750	15,708
Canada	435,254	730,463	372,458	590,460	390,159	449,070
China	317	524	2,283	3,482	—	—
Finland	24,321	41,386	17,085	27,769	13,996	14,385
France	8,110	13,789	2,179	3,280	—	—
Germany, Federal Republic of	3,512	5,884	2,340	3,968	1	27
Guinea	—	—	133	207	—	—
Hong Kong	150	252	1,193	1,981	17	20
Israel	—	—	—	—	20	19
Italy	—	—	6,000	9,659	—	—
Japan	(³)	2	(³)	3	39	35
Korea, Republic of	2,352	3,776	(³)	2	—	—
Mexico	70,817	115,330	72,330	109,916	56,743	58,447
Monaco	136	231	—	—	—	—
Netherlands	4,685	7,532	1,733	2,442	—	—
Norway	28,801	47,325	23,247	36,569	6,898	6,550
Peru	34,010	54,051	23,333	34,186	22,604	24,652
Poland	—	—	822	1,066	—	—
South Africa, Republic of	201	331	—	—	—	—
Spain	26,277	44,747	23,919	37,460	21,192	22,522
Sweden	8	137	—	—	—	—
Taiwan	220	426	200	325	5	12
United Kingdom	1,239	2,114	660	1,028	714	3,613
Yugoslavia	—	—	38	59	—	—
Zaire	13,155	20,720	9,975	13,569	2,636	2,748
Zambia	749	1,159	—	—	—	—
Total ¹	711,554	1,183,523	631,742	991,562	549,137	619,880

¹Data may not add to totals shown because of independent rounding.

²In addition, in 1991, 3,491 tons of zinc anodes was imported from Belgium, Canada, China, France, the Federal Republic of Germany, Hong Kong, India, Italy, Japan, Republic of Korea, Netherlands, Taiwan, and Thailand.

³Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 35
U.S. IMPORTS FOR CONSUMPTION OF ZINC

Year	Blocks, pigs, slabs ¹		Dross, ashes, and fume (zinc content)		Dust, powder, flakes		
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	
1989	711,554	\$1,183,523	9,031	\$7,856	7,253	\$15,123	
1990	631,742	991,562	6,411	5,942	8,834	17,724	
1991	549,137	619,880	6,483	4,658	15,424	26,169	
	Ores and concentrates (zinc content)		Sheets, plates, strips, other forms		Waste and scrap		Total value ² (thousands)
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	
1989	40,974	\$23,047	3,066	\$5,436	9,367	\$6,674	\$1,241,659
1990	46,684	17,970	929	1,641	31,720	15,101	1,049,940
1991	45,419	22,110	539	877	31,596	14,185	687,879

¹Unwrought alloys of zinc were imported as follows, in metric tons: 1989—632 (\$952,159); 1990—736 (\$1,042,096); and 1991—232 (\$296,198).

²In addition, the value of manufactures of zinc imported was as follows: 1989—\$2,080,347; 1990—\$6,729,670; and 1991—\$1,747,262.

Source: Bureau of the Census.

TABLE 36
U.S. IMPORTS FOR CONSUMPTION OF ZINC PIGMENTS AND COMPOUNDS

	1990		1991	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Lithopone	2,487	\$2,189	1,312	\$1,125
Zinc chloride	2,833	2,595	2,175	2,142
Zinc compounds, n.s.p.f.	604	1,177	221	467
Zinc oxide	49,454	71,998	38,215	43,712
Zinc sulfate	4,204	2,234	4,617	2,384
Zinc sulfide	1,525	3,256	1,566	3,435

Source: Bureau of the Census.

TABLE 37
U.S. IMPORT DUTIES FOR ZINC MATERIALS, JANUARY 1, 1991

Item	HTS No.	Most favored nation (MFN)	Canada	Non-MFN
		Jan. 1, 1991	Jan. 1, 1991	Jan. 1, 1991
Ores and concentrates	2608.00.0030	1.7 per kilogram on lead content	1.1 per kilogram on lead content	3.7 per kilogram on zinc content.
Unwrought metal	7901.11.1250	1.5% ad valorem	1.0% ad valorem	5.0% ad valorem.
Alloys, casting-grade	7901.12.1000	19.0% ad valorem	13.3% ad valorem	45.0% ad valorem.
Alloys	7901.20.0000	19.0% ad valorem	13.3% ad valorem	45.0% ad valorem.
Waste and scrap	7902.00.0000	2.1% ad valorem	Free	11.0% ad valorem.
Hard zinc spelter	2620.11.0000	1.5% ad valorem	1.0% ad valorem	5.0% ad valorem.
Zinc oxide, dry	2817.00.0000	Free	Free	5.5% ad valorem.

TABLE 38
ZINC: WORLD MINE PRODUCTION (CONTENT OF CONCENTRATE
AND DIRECT SHIPPING ORE UNLESS NOTED), BY COUNTRY¹

(Thousand metric tons)

Country	1987	1988	1989	1990	1991*
Algeria	8.9	6.3	6.3	4.2	4.2
Argentina	35.6	36.8	43.2	38.7	39.3
Australia	778.4	759.0	803.0	933.0	1,048.0
Austria	15.7	17.1	14.8	17.9	14.8
Bolivia	39.3	57.0	74.8	103.8	129.3
Brazil	133.4	155.5	178.4	138.0	135.0
Bulgaria*	56.0	56.0	55.6	35.0	31.0
Burma	2.6	1.6	1.4	2.2	1.6
Canada	1,481.5	1,370.0	1,216.1	1,203.2	1,148.2
Chile	19.6	19.2	18.4	25.1	31.0
China*	458.0	528.0	538.0	619.0	650.0
Colombia	—	.1	.4	.4	.4
Congo (Brazzaville)*	2.3	1.8	1.0	1.0	1.0
Czechoslovakia*	7.0	7.0	7.1	7.5	7.0
Ecuador*	.1	.1	.1	.1	.1
Finland	55.1	63.9	58.4	51.7	55.5
France	31.3	31.1	26.7	23.9	27.1
Germany, Federal Republic of:					
Western states	98.9	75.6	63.9	58.1	54.0
Greece	20.7	21.2	25.0	26.7	30.0
Greenland	69.2	77.5	71.5	47.9	—
Honduras	15.4	23.5	37.2	29.6	39.0
India	54.5	61.4	65.4	71.6	75.0
Iran*	30.0	15.0	29.0	26.0	50.0
Ireland	177.0	173.2	168.8	166.5	187.5
Italy	33.1	37.2	43.3	42.5	37.5
Japan	165.7	147.2	131.8	127.3	133.0
Korea, North*	220.0	225.0	230.0	230.0	200.0
Korea, Republic of	23.5	21.8	23.2	22.8	22.5
Mexico	271.5	262.2	284.1	322.5	301.1
Morocco	10.3	10.9	18.7	18.8	35.0
Namibia	39.7	36.7	41.7	37.7	33.1
Norway	22.2	17.8	15.0	17.5	18.9
Peru	612.5	485.4	597.4	576.8	623.0
Philippines	1.1	1.4	1.2	.1	.1
Poland	184.0	184.0	179.0	178.0	144.0
Romania*	41.0	41.0	54.5	15.0	15.0
Saudi Arabia	—	.7	2.6	2.5	2.5
South Africa, Republic of	112.7	89.6	77.3	74.8	66.6
Spain	272.6	274.7	281.7	258.0	260.0
Sweden	218.6	189.0	173.5	157.4	155.0
Thailand	74.0	81.0	91.0	81.0	87.0
Tunisia	5.9	9.4	10.0	7.0	8.0
Turkey ³	42.2	37.5	39.4	36.0	23.0
U.S.S.R.*	810.0	810.0	810.0	750.0	650.0

See footnotes at end of table.

TABLE 38—Continued
**ZINC: WORLD MINE PRODUCTION (CONTENT OF CONCENTRATE
 AND DIRECT SHIPPING ORE UNLESS NOTED), BY COUNTRY¹**

(Thousand metric tons)

Country	1987	1988	1989	1990	1991 [*]
United Kingdom	6.5	5.5	5.8	'6.7	1.0
United States	232.9	256.4	288.3	543.2	² 546.6
Vietnam [*]	5.0	5.5	5.5	5.5	5.5
Yugoslavia	'87.4	'91.2	'94.7	'83.8	75.0
Zaire	74.7	75.7	72.8	'61.8	50.0
Zambia ⁴	30.3	25.2	22.9	'32.1	30.0
Total	'7,187.8	'6,979.8	'7,099.7	'7,319.6	7,282.4

^{*}Estimated. ²Revised.

¹Table includes data available through July 1, 1992.

²Reported figure.

³Content in ore hoisted.

⁴Data are for years beginning Apr. 1 of that stated. Content of ore milled.

TABLE 39
ZINC: WORLD SMELTER PRODUCTION, BY COUNTRY¹

(Thousand metric tons)

Country	1987	1988	1989	1990	1991*
Algeria, primary	² 21.0	² 26.5	¹ 16.8	¹ 15.0	15.0
Argentina:					
Primary	³ 31.7	³ 32.7	³ 31.6	³ 31.5	² 35.8
Secondary	2.6	² 2.7	² 2.7	² 2.7	² 2.8
Total	³ 34.3	³ 35.4	³ 34.3	³ 34.2	² 38.6
Australia:					
Primary ³	307.6	302.5	294.0	³ 304.0	² 324.0
Secondary*	4.5	4.5	5.5	5.5	6.0
Total*	312.1	307.0	299.5	³ 309.5	330.0
Austria, primary and secondary	24.3	23.9	26.1	² 28.3	16.3
Belgium, primary and secondary	² 284.5	² 298.1	² 286.9	² 289.7	² 297.6
Brazil:					
Primary	138.7	139.7	155.9	¹ 149.5	150.0
Secondary	9.4	4.3	6.4	⁴ 4.6	5.0
Total	148.1	144.0	162.3	¹ 154.1	155.0
Bulgaria, primary and secondary	92.0	⁹ 90.0	86.8	⁷ 75.5	60.0
Canada, primary	609.9	703.2	⁶ 669.7	⁵ 591.8	⁶ 660.6
China, primary and secondary*	383.0	⁴ 420.0	451.0	⁵ 550.0	526.0
Czechoslovakia, secondary	1.1	1.4	1.3	1.7	1.7
Finland, primary	150.5	156.1	162.5	¹ 174.9	² 170.4
France, primary and secondary	249.3	² 274.1	² 265.8	² 264.1	² 299.6
Germany, Federal Republic of:					
Eastern states, primary and secondary*	² 21.1	² 20.0	18.5	¹ 12.5	2.0
Western states:					
Primary	³ 350.8	³ 313.4	³ 308.2	³ 300.2	305.5
Secondary	29.3	⁴ 42.9	45.3	37.4	39.0
Total*	401.2	376.3	372.0	350.1	346.5
Hungary, secondary*	.6	¹ 1.6	¹ 1.4	¹ 1.3	1.3
India:					
Primary	68.9	68.9	71.6	⁷ 74.0	² 85.8
Secondary*	.2	.2	.2	.2	.2
Total*	69.1	69.1	71.8	⁷ 74.2	86.0
Italy, primary and secondary	247.0	242.1	259.5	² 264.0	265.0
Japan:					
Primary	591.5	601.1	591.2	605.7	² 640.6
Secondary	74.1	77.1	73.3	81.8	² 90.2
Total	665.6	678.2	664.5	687.5	² 730.8
Korea, North, primary*	210.0	210.0	210.0	² 200.0	175.0
Korea, Republic of, primary	186.1	223.0	240.2	248.2	250.0
Mexico, primary	184.8	192.5	193.3	199.3	² 188.7
Netherlands, primary and secondary	207.1	211.0	203.0	² 208.5	201.0
Norway, primary	116.5	121.2	120.4	125.1	² 124.6
Peru, primary	144.2	123.1	¹ 126.7	120.6	² 154.6
Poland, primary and secondary	177.0	174.0	164.0	132.0	² 125.4
Portugal, primary	5.8	5.5	5.0	⁵ 5.5	5.0
Romania, primary and secondary*	39.0	42.0	42.0	¹ 11.0	10.0

See footnotes at end of table.

TABLE 39—Continued
ZINC: WORLD SMELTER PRODUCTION, BY COUNTRY¹

(Thousand metric tons)

Country	1987	1988	1989	1990	1991 ^a
South Africa, Republic of, primary	96.1	¹ 85.2	85.0	¹ 92.3	² 91.5
Spain, primary and secondary	249.0	256.0	257.0	² 252.7	² 273.4
Thailand, primary	66.9	68.6	68.4	¹ 63.3	² 62.2
Turkey, primary	22.2	22.5	24.2	¹ 20.1	² 17.4
U.S.S.R.: ^a					
Primary	890.0	848.0	862.0	780.0	700.0
Secondary	110.0	115.0	115.0	110.0	100.0
Total	1,000.0	963.0	977.0	890.0	800.0
United Kingdom, primary and secondary	81.4	76.0	79.8	93.3	² 100.7
United States:					
Primary	261.3	241.3	263.1	262.7	² 253.3
Secondary	82.6	88.5	95.1	95.7	² 124.1
Total	343.9	329.8	358.2	358.4	² 377.4
Vietnam, undifferentiated ^a	4.2	4.2	4.2	4.2	4.2
Yugoslavia, primary and secondary	118.1	127.5	119.4	113.7	² 87.4
Zaire, primary	54.9	61.1	54.0	¹ 38.2	23.0
Zambia, primary	21.0	20.2	12.9	¹ 10.5	10.0
Grand total	¹ 7,021.8	¹ 7,163.4	¹ 7,176.9	¹ 7,052.8	7,081.7
Of which:					
Primary	¹ 4,530.4	¹ 4,566.3	¹ 4,566.7	¹ 4,412.4	4,442.8
Secondary	314.4	¹ 338.2	¹ 346.2	¹ 340.9	370.3
Undifferentiated	² 2,177.0	² 2,258.9	² 2,264.0	² 2,299.5	2,268.6

^aEstimated. ^bRevised.

¹Wherever possible, detailed information on raw material source of output (primary—directly from ores, and secondary—from scrap) has been provided. In cases where raw material source is unreported and insufficient data are available to estimate the distribution of the total, that total has been left undifferentiated (primary and secondary). To the extent possible, this table reflects metal production at the first measurable stage of metal output. Table includes data available through July 1, 1992.

²Reported figure.

³Excludes zinc dust.

TABLE 40
ZINC: WORLD MINE
AND PRIMARY
SMELTER CAPACITY,
BY COUNTRY

(Thousand metric tons)

Country	Mine	Smelter
Algeria	15	40
Argentina	42	35
Australia	1,085	345
Austria	20	28
Belgium	—	345
Bolivia	140	—
Brazil	170	169
Bulgaria	40	90
Burma	5	—
Canada	1,360	745
Chile	35	—
China	650	500
Congo	2	—
Czechoslovakia	7	—
Ecuador	1	—
Finland	55	170
France	40	305
Germany	70	410
Greece	30	—
Honduras	45	—
Hungary	1	—
India	140	169
Indonesia	1	—
Iran	105	—
Ireland	200	—
Italy	70	253
Japan	160	864
Korea, North	230	260
Korea, Republic of	25	265
Mexico	320	218
Morocco	20	—
Namibia	42	—
Netherlands	—	205
Norway	20	130
Peru	625	172
Philippines	3	—
Poland	180	137
Portugal	30	11
Romania	45	60
Saudi Arabia	3	—
South Africa, Republic of	70	105
Spain	270	360
Sweden	180	—
Thailand	90	70
Tunisia	10	—

See footnotes at end of table.

**TABLE 40—Continued
ZINC: WORLD MINE
AND PRIMARY
SMELTER CAPACITY,
BY COUNTRY**

(Thousand metric tons)

Country	Mine	Smelter
Turkey	45	25
U.S.S.R.	850	1,130
United Kingdom	1	105
United States	650	370
Vietnam	10	10
Yugoslavia	80	15
Zaire	70	72
Zambia	35	40
Total	8,393	8,363

Sources: U.S. Bureau of Mines and International Lead and Zinc Study Group.

TABLE 41
ZINC: WORLD RESERVES AND
RESERVE BASE, BY CONTINENT AND COUNTRY

(Million metric tons)

Continent and country	Reserves	Reserve base
North America:		
Canada	21	56
Mexico	6	8
United States	16	50
Other	(1)	1
Total	<u>43</u>	<u>115</u>
South America:		
Bolivia	1	1
Brazil	2	3
Peru	7	12
Other	(1)	1
Total	<u>10</u>	<u>17</u>
Europe:		
Finland	1	2
France	1	1
Germany	1	2
Greece	1	1
Ireland	6	8
Italy	2	3
Poland	3	4
Portugal	2	3
Spain	4	7
Sweden	1	3
U.S.S.R.	10	15
Yugoslavia	2	3
Other	2	4
Total	<u>36</u>	<u>56</u>
Africa:		
South Africa, Republic of	3	15
Zaire	5	7
Other	1	4
Total	<u>9</u>	<u>26</u>
Asia:		
China	5	9
India	11	15
Iran	2	6
Japan	4	6
Korea, North	4	6
Thailand	1	1
Turkey	1	2
Other	1	2
Total	<u>29</u>	<u>47</u>
Oceania:		
Australia	17	65
Grand total	<u>144</u>	<u>325</u>

¹Less than 1 million metric tons.

²Data do not add to total shown because of independent rounding.

TABLE 42
**APPARENT PER CAPITA CONSUMPTION OF ZINC METAL FOR
 SELECTED YEARS**

Year	World population	Zinc production (kilograms) ¹	Kilograms per person
1800	910,000,000	*2,000,000	0.002
1850	1,130,000,000	*49,000,000	.043
1900	1,600,000,000	494,000,000	.31
1920	1,800,000,000	618,000,000	.34
1940	2,200,000,000	1,673,000,000	.76
1950	2,564,000,000	1,980,000,000	.77
1960	3,050,000,000	3,044,000,000	1.00
1970	3,721,000,000	4,848,000,000	1.30
1980	4,476,000,000	6,130,000,000	1.37
1985	4,882,000,000	6,673,000,000	1.37
1990	5,329,000,000	*7,041,000,000	1.32
2000	6,285,000,000	*8,500,000,000	*1.35

*Estimated.

¹Three-year production average centering on the year of population estimate, i.e. production for 1980, production in 1979, 1980, and 1981 was averaged. Production for 1990 and 2000 are not averages but estimates for these years only.

²Source: World Almanac and Book of Facts, 1982.

³Source: Bureau of the Census, Center for International Research.

ZIRCONIUM AND HAFNIUM

By David A. Templeton

Mr. Templeton is a physical scientist with the Branch of Industrial Minerals. He has covered zirconium and hafnium for about 4 years. Domestic survey data were prepared by the Section of Metals Data. World production data are provided by country specialists in the Division of International Minerals, and the data were compiled by Mr. Harold D. Willis.

Mine production of zircon—the primary ore mineral of zirconium and hafnium metal, oxide, and chemicals—remained at just above the 100,000-metric-ton level for the second year in a row. Zircon was recovered from two heavy-mineral mining operations in Florida and at a tailings rework project in New Jersey. As well as being a source for the aforementioned products, which collectively account for approximately 30,000 tons of annual consumption, zircon is also extensively used in refractories, foundry sands (including investment casting), and ceramic opacification. Zirconium and hafnium, which are both contained in zircon at a ratio of about 50:1, are mainstay nuclear metals used in reactor cores. Commercial-grade zirconium, unlike nuclear-grade, contains hafnium and is used in the chemical process industries because of its corrosion resistance. The two metals are only separated for nuclear purposes and for the following reason: Zirconium is relatively transparent to thermal neutrons, the steam-generating products of nuclear fission, and hafnium, having the opposite effect, is an excellent sink or absorber of them. It is for these reasons that zirconium-clad fuel rods and hafnium control rods make up the core of the reactor.

DOMESTIC DATA COVERAGE

Data in this report are collected from an assortment of sources. U.S. mine production of zircon sand is obtained by directly surveying the three producing mines, all of which responded. By collecting zircon consumption data from specific industries that consume it,

information regarding the production of downstream products can be obtained. Examples include oxide, metal, chemicals, refractories, abrasives, flour, frits, etc. However, due to lack of participation from larger industries (e.g., refractories), it is difficult to publish reliable consumption figures, so an estimate is used instead. In smaller industries where there may be only a small set of companies within the survey population representing an entire end use (e.g., abrasives, metal, chemicals), the data are not available for company proprietary reasons. It is for all these reasons that only estimated consumption numbers can be used for industry groupings.

Environmental Requirements

Processing of some mineral sands, and only by certain methods, results in the concentration of radioactive elements in the waste or byproduct streams. Monazite and xenotime, both rare-earth thorium phosphates, are culpable minerals in most cases because 100% separation of the full heavy-mineral suite is impossible to obtain within economic considerations. Even if it could all be removed, monazite inclusions within the zircon grains and/or ionic substitution of uranium, thorium, radium, and/or actinium for the zirconium and/or hafnium within the mineral lattice still results in some radioactive contamination. Monazite processing to obtain rare-earth elements results in a large byproduction of thorium nitrate. Because demand for thorium cannot keep pace with that for rare earths, large amounts of money have been spent to dispose of it in the low-

level storage sites at Barnwell, SC, and Hanford, WA. Processing of zircon and the titanium minerals is much less of a problem, because of lower concentrations in the bulk product that the consuming industries receive from the mining industry. However, because concentration does occur, in proportion to the throughput for a given sand's analysis, in the zirconium chemical and metal industries, they have long been adhering to federal code in the handling, storage, and disposal of the byproduct "source material." Generally, if the combined weight of uranium and thorium exceeds 0.05%, materials are considered to be sources for these radioactive elements. Domestic requirements for licensing source material, definitions, exemptions, and other pertinent information is found in the Code of Federal Regulations, Energy, 10, Part 40 (10CFR40).

Japan enacted strict importation and industrial guidelines on June 6, 1991, as a result of the July 1990 finding of radiation levels originating from titanium dioxide pigment plant wastes dumped in Okayama Prefecture. Basically, the policy, which was created via the cooperation and input from four government entities, addresses the following key areas: protection of residential areas near plants and dump sites, air quality, strict containment of ore and processing wastes, and limits on the allowable dose rates exhibited by ores.

Corrective measures to clean up two areas where the zirconium industry was born, in Albany, OR, have been completed after several years of debate at local, State, and Federal levels. The U.S. Bureau of Mines original Northwest

Electrodevelopment Laboratory (now the Albany Research Center), where the Kroll Process to produce zirconium sponge was invented, and Teledyne Wah Chang Albany have both completed their individual efforts.

ANNUAL REVIEW

Legislation and Government Programs

Negotiations neared conclusion between the U.S. Advanced Battery Consortium and the Ovonic Battery Co. of Troy, MI. Comprising the consortium are the Big Three domestic automobile manufacturers, the Electric Power Research Institute, and the Department of Energy. With funds of \$260 million available, the goal is to award multiple contracts for developing electric-car battery technology. Ovonic has developed a nickel-metal hydride battery as an alternative to nickel-cadmium and has already signed licensing agreements with companies worldwide. Among the signatories are consumer electronic firms and other battery companies. At least two of the agreements are with Asian automobile producers and are geared toward developing a prototype electric car, with the ultimate intent of mass production and consumer acceptance. Twenty-five years of research on rare-earth-nickel hydrides has overcome the obstacles to produce a viable battery capable of rechargeable service. The new battery, in which zirconium is a principal ingredient (also Ti, V, and Ni), is much simpler and more efficient to produce and offers higher energy densities per ounce of battery. Zirconium serves as one of the hydrogen storage elements (V and Ti too) and provides mechanical integrity to the hydrided and embrittled electrode when the battery is charged.

The Environmental Protection Agency's Office of Toxic Substances announced in the November 21, 1991, Federal Register that a priority review of refractory ceramic fibers (RCF's) was to begin. RCF's are produced by attenuating, via blowing or spinning, molten metal oxides such as zirconia, alumina, boria, silica,

and/or magnesia. Just as with many types of airborne particulate matter, RCF's were linked to various lung conditions in hamsters and rats. Current exposure estimates based on industry and available literature are 0.1 to 6.4 (sic, lowest high-end exposure because efficient production technology provides inherent containment) fibers per cubic centimeter (f/cc) for manufacturing environments, 0.02 to 56 f/cc for processing, and 0.01 to 25 f/cc during normal use. The notice also stated that the Occupational Safety and Health Administration was developing formal permissible exposure limits in cooperation with the RCF industry.

Issues

In 1989, the United States imported a total of 92 tons of zirconium metal from the U.S.S.R. There was none imported in 1990, but in 1991, the United States imported 1,388 kg of zirconia, either natural baddeleyite or synthetic, from the U.S.S.R. Since December 1990, the U.S. Bureau of Mines has received numerous inquiries from domestic brokers, traders, and import/export firms seeking potential markets for zirconium and hafnium, as well as other minerals and metals. All of the material being marketed was produced in the Soviet Union. The marketing attempt has thus far been mostly unsuccessful. Among the many reasons are: impurities and costs are too high; the markets are esoteric; and, sourcing another's material would impose on producer-consumer relationships that are, in some cases, decades old. Excluding the U.S.S.R., there are only three burgeoning producers of these metals; two of them are in the United States, the other in France. With two of the world's three non-Soviet producers located here, the effort would probably fare better elsewhere. More on this subject is under the World Review section at the end of the report.

Production

Mine production of zircon was again sharply lower than the level seen at the

end of the 1980's when the zircon market was at its peak. The 1990-91 production level of 100,000 tons is almost 20% below previous levels that neared 120,000 tons. Apparent consumption was also significantly lower and exemplifies the general economic slowdown, with no one individual consumption sector bearing the brunt. Domestic apparent consumption after the bust fell to consistent/constant levels approximating 105,000 tons, down 30% compared with the prebust, 3-year average of 152,000 tons. And while lower production accounts for a considerable reduction in apparent consumption, the reversal of imports and exports has exacerbated it. Imports are at drastically lower levels, between 50% and 75%, and exports are generally 50% higher, with the exception of 1989. (See table 1.)

Zirconium and hafnium metal continued to be produced at Albany, OR, and Ogden, UT, by Teledyne Wah Chang and Western Zirconium, respectively. Both companies used the Bureau-developed Kroll process to produce sponge metal. Both metals were also produced in the form of crystal bar. In the first method, zircon sand is chlorinated in a fluidized bed. The zirconium (plus hafnium) silicate thus becomes a tetrachloride of zirconium, hafnium, and silicon. The latter is removed, and the former two are separated via solvent extraction when nuclear-grade zirconium is required. The metal tetrachlorides are reacted with magnesium metal. The resulting magnesium chloride salt forms in bubbles throughout the melt. Once vacuum distilled to evacuate the magnesium chloride, the resulting porous mass of zirconium is quite sponge-like in appearance.

Zirconium crystal bar and hafnium crystal bar was also produced by sublimating each individual metal in an iodide atmosphere in the presence of a heated wire, itself composed of the particular metal being produced. The metal halide gas deposits its metal constituency on the wire, and the gas returns to further decompose the feed metal. The resulting bar is multifaceted from the growth of single crystals along

the length of the original wire, thus the term "crystal bar."

Countless other end products were also produced from zircon. High-volume production included refractory bricks and shapes, alumina-zirconia abrasives, foundry sands and investment castings, milled and micronized zircon, zirconium chemicals, and zirconia. The latter two are further used to produce many other products used in a wide range of applications. Examples of high-value production are cubic zirconia, technical zirconia ceramics, superalloy castings, zirconia textile refractories, and specialty chemicals.

Markets and Prices

The continued decline in zircon prices had a clear effect on world production and was most evident in Australia's output, which nearly halved, and the United States's steady rate after the marked drop last year. Although the Republic of South Africa showed a significant increase as a result of the expansion's completion, it was reported that much of the added production was stockpiled.

Continued recessionary conditions in the world's major zircon-consuming economies—viz., Europe, Japan, and the United States—put further downward pressure on the price of zircon. Exacerbating the decline was substitution in refractories, mainly by high-magnesia spinels and especially in Japan. The price for lower grades of baddeleyite (96% to 98% ZrO₂) was also affected by the decline in zircon prices. This grade competes with zirconia produced from zircon either by arc furnace, plasma torch, or wet chemistry (caustic fusion) methods. (See table 3.)

World Review

Australia.—Australian producers drastically scaled back production in response to weak demand from recessed economies and substitution inspired by recent record-high prices. As prices continued to reel downward, some mines closed temporarily or permanently while

other large projects opted to significantly scale back and/or switched to mining lower cost deposits. As was the situation in the United States, deposits under consideration for future development were generally put on hold, canceled, or paced to bring mines online coincident with the expected turnaround, estimates for which spanned the remainder of the decade.

Construction started in January on a zircon refractory plant, and the plant opened in December. The plant is near Consolidated Rutile Ltd.'s (CRL) zircon sand processing plant in Pinkenba, Brisbane, Queensland. Noncoincidentally, CRL is a 45% joint-venture partner with the French glass conglomerate SEPR, which holds 55% interest in the joint venture, SEPR Australia Pty. Ltd.

India.—Indian Rare Earths Ltd. and Kerala Minerals and Metals Ltd., both Government companies, sought to enter a joint venture to exploit a deposit at Neendakara, on the coast of the Arabian Sea, in Kerala. The 22-km-long ore body is 4 km wide, 1 km onshore and 3 km offshore, and was estimated to contain reserves valued at \$10 billion dollars.

Work began on a titanium and zirconium sponge metal production plant in the Chidambaranar district of Tamil Nadu. The project is managed by the Nuclear Fuel Complex in Hyderabad and has design capacity to annually produce 1,000 tons of titanium and 300 tons of zirconium. Feed material for the plant will come from another facility under development in Manavalakurichi, also in Tamil Nadu. The two-phase project is planned first to increase dry frit production to 600 tons per year, and then to produce raw material for cubic zirconia diamond simulants.

Indonesia.—An alluvial gold and heavy-mineral operation that began in 1988 in Central Kalimantan neared completion. The Ampalit Mine, estimated to contain 13,500 tons of zircon, has produced a heavy-mineral byproduct containing roughly 50% zircon or roughly 33% ZrO₂. Original intentions to upgrade the

zircon to a world standard of 65% ZrO₂ were either put on hold or only nominally successful, as evidenced by published advertisements seeking bids on an 8- to 10,000-ton stockpile containing 49% to 51% ZrO₂. The company, P.T. Ampalit Mas Perdana, is jointly owned by an Australian company, Plesart Pty. Ltd. (85%), and an Indonesian company, P.T. Wisma Budi Kesti (15%). Company plans were to move plant equipment to another site 13 km south following depletion of the deposit. The new deposit was estimated to have reserves capable of producing more than 28,000 tons of zircon over its 7-year life. The Bureau's country specialist estimated that 1989 production was 2,500 tons. This estimate has been used to amend the world production table for the years 1989 through 1991.

Japan.—Magnesium Elektron Ltd., the United Kingdom parent company of the Flemington, NJ-based subsidiary, began chemical production at two sites in Japan through another Alcan Group sibling, the Nippon Light Metal Co. Nikkei-MEL, the new joint venture, planned manufacture of zirconium chemicals for catalysts and optical fibers, as well as traditional markets.

Sierra Leone.—Pioneer Resources set ground for a formal agreement with its subsidiary, Hazcare Pty. Ltd., to move ahead with the development of the Rotifunk and Sembehun heavy-mineral deposits. The mineral assemblages are similar to the nearby Pejabu deposit that is operated by Sierra Rutile and will serve as an example in the economic modeling. The inferred resources total 3.72 million tons, of which 130,000 tons is zircon, the remainder ilmenite and rutile. A drilling program to measure and prove up the ore body and a feasibility study were to follow/predicate the agreement.

Sierra Rutile produced 1,119 tons of zircon in 1991. Production was halted due to the severely depressed market. Long stockpiled while mining and mineral recovery concentrated on titanium minerals, current and future working

deposits are of sufficient zircon grade to dress the full suite of heavy minerals. Sierra Rutile Ltd. uses a U.S. patented amine froth flotation process that separates an upgradable, zircon-rich concentrate from the titanium minerals. The impetus for the development was the gradual accumulation of a 200,000-ton stockpile of considerable grade coupled with the necessity of improving on traditional separation techniques to improve the metallurgical balance of the final products, ilmenite, rutile, and zircon.

South Africa, Republic of.—Shell South Africa Minerals Div. and Rhombus Exploration Ltd. undertook a comprehensive feasibility study on three deposits within 40 km of the Richards Bay port. The study was expected to be completed in 1992. The deposit, in the Empageni district of northern Natal, was estimated to contain a combined heavy-mineral resource of 10 million tons, 1.1 million tons of which is zircon. Preliminary plans envisaged annual zircon production of 30,000 tons for 20 years.

U.S.S.R.—With the breakup of the U.S.S.R. came the first information concerning zirconium production facilities there. Long suspected by many and known by some, the existence of plants there was first strongly evidenced last December (1990) by a spate of marketing efforts by domestic commodity traders and brokers. After the first full year of marketing, the writer had received almost 100 calls for information concerning zirconium markets in the United States. Most of the investigators described lots, many of which were said to be warehoused in Antwerp, Rotterdam, and Amsterdam or elsewhere in Europe, pertaining to zirconium ingot, crystal bar, plate, and rods. Many of the efforts were duplicated, as descriptions were identical or quite similar. With the non-most-favored-nation (Non-MFN) status remaining in place for all of the Republics except for Lithuania, Latvia, and Estonia, which quickly acted to be recognized as MFN, the prohibitive import tariffs of 25% and 45% on

unwrought and wrought metal remained in place.

Insofar as plants in the former U.S.S.R. are concerned, the only information that has been gleaned relates to two plants, one in Dnieprodzer, Ukraine, and the other in Glasov, Russia. The former is called the Pridneprovsky Chemical Plant and is said to produce zirconium ingots and zirconium fluoride through a calciothermic reduction process. The Chepetsky Mechanical Plant, in Glasov, is said to specialize in producing zirconium crystal bar.

Kovdor Mining and Dressing Mill produces apatite, baddeleyite, and iron ore on the Kola Peninsula in Russia. The mining concern made arrangements in September for BM Trading AS to modernize the production of each ore in a three-phase project, the first of which addresses baddeleyite, a natural zirconium oxide mineral. The goal is to increase the percentage of baddeleyite extracted from the ore to 40%.

Current Research

Westinghouse Electric Corp.'s new nuclear alloy, Zirlo,¹ was further tested in 1991. The alloy, which began its first field tests in 1988 at North Anna in Virginia, is lower in tin than the zircalloys and, in addition, has 1% niobium. The reported result is an alloy with higher strength and corrosion resistance that can remain in the pile of pressurized water reactors longer without the deleterious growth and creep rates suffered by other alloys in this extreme environment.

Among other recent developments in nuclear fuel was Westinghouse's integral fuel burnable absorber (IFBA), a zirconium boride coating on uranium fuel pellets. The IFBA replaces former modes of absorbers, which are mounted as assemblies in control rod guide thimbles.

The catalytic affects of zirconium hydride on hydrocarbons (alkanes) were established by French researchers at the Institut de Recherches sur la Catalyse in Villeurbanne. Neopentane was converted to isobutane and methane; isobutane was converted to propane and methane; and,

propane was converted to ethane and methane. At temperatures of 50° C, the hydrogenolysis conversions were controllable so that one or the other of the end products was obtainable, but at higher temperatures the primary and secondary reactions had higher rates of hydrogenolysis and both end products were obtained. The catalytic performance was attributed to the strong bonding between the zirconium atoms and the silica support and the high electrophilic nature of the zirconium hydride complex.²

Martin Marietta Energy Systems, Inc., received a patent covering the preparation and composition of a new ceramic alloy containing oxides of cerium, hafnium, and zirconium metal. The new material is "transformation toughened," just as in other zirconias, by the volumetric expansion that occurs upon the internal structural transformation from the tetragonal to monoclinic phase. Having the general formula $Ce_xHf_yZr_{(1-x-y)}O_2$, the alloy typically contains between 5 and 15 mol percent ceria, 40 mol percent hafnia, and the balance zirconia.

Two separate innovations concerning the production of yttria-stabilized zirconia via wet chemistry were developed in Japan. The first method utilized an inorganic zirconia sol, as opposed to conventional organic alkoxide, as the starting raw material. Yttrium oxide was then added, and the mixture was powdered and calcined. The sintered product was then comminuted a final time. Because particle size of the starting material can be adjusted, the method is said to be amenable to many molding methods and end products. In the other process, developed by the Tokyo-based Chichibu Cement Corp. and funded by Japanese Government Science and Technology Corp., zirconium oxychloride and yttrium chloride were blended with urea and water prior to autoclaving. Upon increase in temperature, the urea decomposes into ammonium and carbon dioxide; the ammonium in turn reacts with the precursor chemicals, thus causing a slurry of zirconia and yttria to precipitate. Residual ammonium ions were removed from the slurry via a

proprietary technique, and a crystalline solid results.

Efforts by Japan's National Aerospace Laboratory to develop materials with the heat resistance of ceramics and the strength of metals has resulted in several "functionally gradient materials" (FGM) that contain zirconia. Because dissociation can occur in composites and coatings due to dissimilar rates of thermal expansion, the idea behind FGM's is to join the two materials via graduating from one to another on an atomic scale so that there is no joint for faults to arise (e.g., fatigue, rupture, galling, etc.) The 5-year project, which began in 1986, had, by 1989, produced two zirconia-specific FGM's, one incorporating nickel and the other a nickel-chromium alloy. Early methods for producing FGM's relied on plasma spraying or chemical vapor deposition, processes that took hours to produce. In this, the last year of the project, two companies have produced FGM's using methods that apply electrical current to starting materials under pressure. A titanium and partially stabilized zirconia FGM was developed by Fujitsu Ltd. that changes in 10% steps from one material to the other. Sumitomo Coal Mining Co. used a plasma spark technique to produce a FGM plate that changes from 100% stainless steel to 100% zirconia in a five-stage gradient. The precursor powders are pressed between two electrodes, and the applied current causes sparking between individual grains. The particles are joined where spark paths develop, and the resulting electrical resistance causes further sintering.

OUTLOOK

Zircon is a difficult commodity to supply in that there are so many different consumer markets that depend on it for their raw material supply. Zircon supply is directly related to and dependent on the demand and ensuing supply of titanium minerals for metal and pigment (white) production. Within the confines of one mining business, it is relatively simple to match production with the needs of a specific set of customers, even in their

dissociated markets. Expanded to the global marketplace and its independent producers, coordinated production would be difficult to achieve even if demand for the myriad sectors of consumers could be predicted with certainty. With zircon being so codependent on the supply and demand sides and all the variables each side raises now and then, it is no wonder that zircon has seen the wild swings of the 1970's and 1980's. There have been three significant shortage events in that period: the early 1970's, the early 1980's, and again in the late 1980's. If the 7- to 10-year cycle continues, another bust can be expected near the end of the present decade after a slow and steady rebound. Unexpected heavy demand in one of the large consuming industries could certainly bring it sooner. For example, a surge in infrastructure spending would boost demand for steel and other metallurgical refractories. Likewise, if manufacturing companies increased investment in modern plant and capital equipment, alumina-zirconia abrasives and foundries would demand more zircon. However unlikely, new chemical plants and nuclear powerplants would increase demand for zirconium metal.

¹Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

²Chemical & Engineering News. Supported Zr-H Catalyst Activates C-H Bonds. V. 70, No. 5, Feb. 3, 1992, p. 20.

OTHER SOURCES OF INFORMATION

Industrial Minerals.
International Strategic Minerals Inventory.
U.S. Geological Survey, Circular 930-L.
Mining Journal.
Nuclear Assurance Corp.'s Zirconium Status Report.
Roskill Information Services Ltd., Economics of Hafnium, 2d ed., 1990.
Roskill Information Services Ltd., Economics of Zirconium, 6th ed., 1990.

TABLE 1
SALIENT U.S. ZIRCONIUM STATISTICS

(Metric tons)

	1987	1988	1989	1990	1991
Zircon:					
Production:					
Concentrates	W	117,606	118,388	102,073	103,140
Milled zircon	42,394	64,393	54,699	43,886	44,403
Exports	20,054	21,794	48,071	30,195	31,333
Imports for consumption ¹	67,917	76,331	73,129	26,783	35,706
Consumption, apparent ¹	132,800	176,991	145,683	¹ 102,713	111,829
Stocks, Dec. 31: Dealers and consumers ²	39,218	34,370	32,133	² 28,081	23,765
Zirconium oxide:					
Production ³	⁶ 5,553	⁶ 8,845	10,030	7,483	9,747
Exports	1,206	1,809	NA	NA	NA
Imports for consumption	1,274	1,089	NA	NA	NA
Consumption, apparent	3,800	3,548	NA	NA	NA
Stocks ³	1,213	507	502	737	731

¹Revised. NA Not available. W Withheld to avoid disclosing company proprietary data.

²Includes insignificant amounts of baddeleyite.

³Excludes foundries.

⁴Excludes intermediate oxide associated with metal production.

TABLE 2
ESTIMATED CONSUMPTION OF ZIRCON, BY END USE, BASED ON
TOTAL APPARENT CONSUMPTION

End use	1990	1991
Zircon refractories ¹	¹ 16,000	18,000
AZS refractories ²	8,000	9,000
Zirconia and AZ abrasives ³	W	W
Alloys ⁴	W	W
Foundry applications	³ 30,000	32,000
Other ⁵	³ 35,000	38,000
Total	¹ 103,000	112,000

¹Revised. W Withheld to avoid disclosing company proprietary data; include in "Total."

²Dense and pressed zircon brick and shapes.

³Fused cast and bonded alumina-zirconia-silica-base refractories.

⁴Alumina-zirconia-base abrasives.

⁵Excludes alloys more than 90% zirconium.

⁶Includes chemicals, zirconium metal, welding rods, sandblasting, and other miscellaneous uses.

TABLE 3
PUBLISHED YEAREND PRICES OF ZIRCONIUM AND HAFNIUM MATERIALS

Specification of material	1990	1991
Zircon:		
Domestic, standard-grade, f.o.b. Starke, FL, bulk, per short ton ¹	\$368.00	\$331.00
Domestic, 75% minimum quantity zircon and aluminum silicates, Starke, FL, bulk, per short ton ¹	204.00	184.00
Domestic, premium-grade zircon, Starke, FL, bulk, per short ton ¹	—	368.00
Imported sand, minimum 65% ZrO ₂ , f.o.b., bulk, per metric ton ²	309.00-386.00	228.00-266.00
Imported sand, minimum 65.5% to 66% ZrO ₂ , f.o.b., bulk, per metric ton ²	348.00-425.00	228.00-266.00
Imported sand, minimum 66% ZrO ₂ , f.o.b., bulk, per metric ton ²	386.00-464.00	228.00-266.00
Domestic, granular, bags, bulk rail, from works, per short ton ³	300.00-600.00	300.00-600.00
Domestic, milled, 200- and 325-mesh, rail, from works, bags, per short ton ³	350.00-800.00	350.00-800.00
Baddeleyite, imported concentrate⁴		
96% to 98% ZrO ₂ , minus 100-mesh, c.i.f. Atlantic ports, per pound	.60- .75	.45- .60
99%+ ZrO ₂ , minus 325-mesh, c.i.f. Atlantic ports, per pound	1.07- 1.20	1.07- 1.20
Zirconium oxide:⁵		
Powder, commercial grade, drums, 2,000-pound minimum, per pound	2.00- 7.00	2.00- 7.00
Electronic, same basis, per pound	3.50- 8.00	3.50- 8.00
Insulating, stabilized, 325° F, same basis, per pound	4.50	4.50
Insulating, unstabilized, 325° F, same basis, per pound	5.00	5.00
Dense, stabilized, 300° F, same basis, per pound	3.00	3.00
Zirconium oxychloride: Crystal, cartons, 5-ton lots, from works, per pound ³	.91- 1.04	.91- 1.04
Zirconium acetate solution:³		
25% ZrO ₂ , drums, carlots, 15-ton minimum, from works, per pound	.97	.97
22% ZrO ₂ , same basis, per pound	.78	.78
Zirconium hydride: Electronic-grade, powder, drums, 100-pound lots, from works, per pound ³	.31- .75	.31- .75
Zirconium:⁵		
Powder, per pound	75.00-150.00	75.00-150.00
Sponge, per pound	9.00- 12.00	9.00- 12.00
Sheets, strip, bars, per pound	20.00- 50.00	20.00- 50.00
Hafnium: Sponge, per pound⁵	75.00- 95.00	75.00- 95.00

¹E. I. du Pont de Nemours & Co. Inc. price lists. Apr. 1, 1990, and July 8, 1991, respectively.

²Industrial Minerals (London). No. 279, Dec. 1990, p. 79; and No. 291, Dec. 1991, p. 63.

³Chemical Marketing Reporter. V. 238, No. 27, Dec. 31, 1990, p. 40; and v. 240, No. 26, Dec. 23, 1991, p. 32.

⁴The Applegate Group and American Vermiculite Corp. baddeleyite price lists.

⁵American Metal Market. V. 98, No. 251, Dec. 28, 1990, p. 6; and V. 99, No. 239, Dec. 13, 1991, p. 6.

TABLE 4
U.S. EXPORTS OF ZIRCONIUM, BY CLASS AND COUNTRY

Class and country	1990		1991	
	Metric tons	Value (thousands)	Metric tons	Value (thousands)
Ore and concentrates:				
Argentina	177	\$276	445	\$390
Australia	—	—	92	128
Belgium	1,979	1,223	171	111
Brazil	25	20	694	310
Canada	2,284	2,066	6,074	3,829
Chile	90	159	36	53
Colombia	879	1,449	1,521	1,663
Costa Rica	27	68	20	23
Dominican Republic	116	197	92	115
Ecuador	274	358	419	314
Egypt	141	195	196	140
France	651	591	724	532
Germany, Federal Republic of	8,508	6,609	5,048	4,595
Ireland	43	8	—	—
Italy	387	283	239	117
Japan	3,834	932	584	186
Korea, Republic of	219	167	166	219
Mexico	6,391	3,618	6,303	2,721
Netherlands	13	22	5,993	2,656
Pakistan	36	49	97	106
Peru	54	68	200	137
Singapore	277	152	170	163
Spain	43	5	17	11
Taiwan	945	572	36	42
Thailand	18	22	—	—
U.S.S.R.	989	674	—	—
United Kingdom	892	400	458	642
Uruguay	18	35	59	60
Venezuela	759	732	1,078	945
Other	125	151	403	398
Total¹	30,195	21,101	31,333	20,607
Unwrought zirconium and waste and scrap:				
Belgium	25	240	13	147
Canada	2	113	4	165
France	1	20	13	275
Germany, Federal Republic of	5	189	44	504
Italy	26	152	9	96
Japan	48	1,052	94	3,442
Netherlands	27	146	14	192
Switzerland	2	71	6	185
Taiwan	8	179	5	62

See footnotes at end of table.

TABLE 4—Continued
U.S. EXPORTS OF ZIRCONIUM, BY CLASS AND COUNTRY

Class and country	1990		1991	
	Metric tons	Value (thousands)	Metric tons	Value (thousands)
Unwrought zirconium and waste and scrap—Continued				
Thailand	(¹)	\$5	—	—
United Kingdom	35	778	25	\$524
Other	7	114	11	191
Total¹	188	3,057	238	5,785

¹Data may not add to totals shown because of independent rounding.

²Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF ZIRCONIUM AND HAFNIUM, BY CLASS AND COUNTRY

Class and country	1990		1991	
	Metric tons	Value (thousands)	Metric tons	Value (thousands)
Zirconium ore and concentrates:¹				
Australia	11,998	\$5,600	20,865	\$8,383
Canada	20	15	—	—
France	76	349	23	110
Japan	—	—	13	156
Netherlands	—	—	20	14
South Africa, Republic of	14,381	5,833	14,615	4,725
United Kingdom	293	574	166	371
Other	14	37	4	13
Total²	26,783	12,407	35,706	13,772
Zirconium, unwrought and waste and scrap:				
Canada	41	299	24	141
France	46	209	53	358
Germany, Federal Republic of	—	—	37	363
Japan	5	98	36	239
Sweden	25	198	6	34
United Kingdom	11	74	38	184
Other	—	—	3	28
Total²	128	880	197	1,347
Hafnium, unwrought and waste and scrap:				
France	8	1,436	3	475
Germany, Federal Republic of	1	215	(³)	14
United Kingdom	(³)	12	—	—
Total²	9	1,662	3	489

¹Australia and the Republic of South Africa are believed to be point of origin; other countries are point of shipment.

²Data may not add to totals shown because of independent rounding.

³Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 6
ZIRCONIUM MINERAL CONCENTRATES:
WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country	1987	1988	1989	1990	1991*
Australia	456,590	480,049	511,000	¹ 437,000	292,000
Brazil ²	18,131	28,029	32,970	¹ 16,907	20,000
China*	15,000	15,000	15,000	15,000	15,000
India*	10,000	15,000	17,200	18,000	18,200
Indonesia*	—	—	2,500	2,500	2,500
Malaysia	17,828	25,671	18,704	4,279	³ 5,579
Sierra Leone	—	—	—	—	³ 1,119
South Africa, Republic of**	140,000	150,000	¹ 150,000	¹ 151,536	230,000
Sri Lanka	⁴ 4,000	³ 3,000	² 21,983	¹ 19,727	³ 26,123
Thailand	1,532	5,098	1,496	⁴ 490	² 2,573
U.S.S.R.*	90,000	90,000	90,000	¹ 85,000	80,000
United States	W	117,606	118,388	102,073	³ 103,140
Total	753,081	929,453	¹979,241	¹852,512	796,234

*Estimated. ¹Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

²Includes data available through June 3, 1992.

³Includes production of zircon and caldasite.

⁴Reported figure.

**Includes production of zircon and baddeleyite.